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## (54) Polymeric gas or air filled microballoons usable as suspensions in liquid carriers for ultrasonic echography

Mit Gas oder Luft gefüllte polymere Mikrokapseln, verwendbar in Form von Suspensionen bei flüssigen Trägern für Ultraschall-Echographie

Microcapsules polymères remplies d'air ou de gaz, utilisables sous forme de suspensions dans les supports liquides pour l'échographie ultrasonore

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EP 0 458 745 B2

## Description

[0001] The present invention concerns air or gas filled microcapsules or microballoons enclosed by an organic polymer envelope obtainable by the steps of

(1) emulsifying a hydrophobic organic phase into a water phase so as to obtain droplets of said hydrophobic phase as an oil-in-water emulsion in said water phase;

(2) adding to said emulsion a solution of at least one polymer in a volatile solvent insoluble in the water phase, so that a layer of said polymer will form around said droplets;

(3) evaporating said volatile solvent so that the polymer will deposit by interfacial precipitation around the droplets which then form beads with a core of said hydrophobic phase encapsulated by a membrane of said polymer, said beads being in suspension in said water phase;

(4) subjecting said suspension to freeze drying conditions; wherein said hydrophobic phase is selected so that it evaporates substantially simultaneously with the water phase and is replaced by air or gas, whereby dry, free flowing, readily dispersible microballoons are obtained;

(5) wherein said polymer may be dissolved in said hydrophobic phase, so that steps (2) and (3) can be omitted and the polymer membrane will form by interfacial precipitation during step (4).

[0002] The microcapsules or microballoons can be dispersed or suspended in aqueous media and used in this form for oral, rectal and urethral applications or for injection into living beings, for instance for the purpose of ultrasonic echography and other medical applications.

[0003] The invention also comprises a method for making said microballoons in the dry state, the latter being instantly dispersible in an aqueous liquid carrier to give suspensions with improved properties over existing similar products. Hence, suspensions of the microballoons in a carrier liquid ready for administration are also part of the invention.

[0004] It is well known that microbodies or micro-globules of air or a gas, e.g. microspheres like microbubbles or microballoons, suspended in a liquid are exceptionally efficient ultrasound reflectors for echography. In this disclosure the term of "microbubble" specifically designates air or gas microspheres in suspension in a carrier liquid which generally result from the introduction therein of air or a gas in divided form, the liquid preferably also containing surfactants or tensides to control the surface properties and the stability of the bubbles. In the microbubbles, the gas to liquid interface essentially comprises loosely bound molecules of the carrier liquid. The term of "microcapsule" or "microballoon" designates preferably air or gas bodies with a material boundary or envelope of molecules other than that of the carrier liquid, i.e. a polymer membrane wall. Both microbubbles and microballoons are useful as ultrasonic contrast agents. For instance injecting into the bloodstream of living bodies suspensions of gas microbubbles or microballoons (in the range of 0.5 to 10 µm) in a carrier liquid will strongly reinforce ultrasonic echography imaging, thus aiding in the visualization of internal organs. Imaging of vessels and internal organs can strongly help in medical diagnosis, for instance for the detection of cardiovascular and other diseases.

[0005] The formation of suspensions of microbubbles in an injectable liquid carrier suitable for echography can be produced by the release of a gas dissolved under pressure in this liquid, or by a chemical reaction generating gaseous products, or by admixing with the liquid soluble or insoluble solids containing air or gas trapped or adsorbed therein.

[0006] For instance, in US-A-4,466,442 (Schering), there are disclosed a series of different techniques for producing suspensions of gas microbubbles in a sterilized injectable liquid carrier using (a) a solution of a tenside (surfactant) in a carrier liquid (aqueous) and (b) a solution of a viscosity enhancer as stabilizer. For generating the bubbles, the techniques disclosed there include forcing at high velocity a mixture of (a), (b) and air through a small aperture; or injecting (a) into (b) shortly before use together with a physiologically acceptable gas; or adding an acid to (a) and a carbonate to (b), both components being mixed together just before use and the acid reacting with the carbonate to generate $CO_2$ bubbles; or adding an over-pressurized gas to a mixture of (a) and (b) under storage, said gas being released into microbubbles at the time when the mixture is used for injection

[0007] One problem with microbubbles is that they are generally short-lived even in the presence of stabilizers. Thus, in EP-A-131.540 (Schering), there is disclosed the preparation of microbubble suspensions in which a stabilized injectable carrier liquid, e.g. a physiological aqueous solution of salt, or a solution of a sugar like maltose, dextrose, lactose or galactose, is mixed with solid microparticles (in the 0.1 to 1 µm range) of the same sugars containing entrapped air. In order to develop the suspension of bubbles in the liquid carrier, both liquid and solid components are agitated together under sterile conditions for a few seconds and, once made, the suspension must then be used immediately, i.e. it should be injected within 5-10 minutes for echogrophic measurements; indeed, because the bubbles

are evanescent, the concentration thereof becomes too low for being practical after that period.

**[0008]** Another problem with microbubbles for echography after injection is size. As commonly admitted, microbubbles of useful size for allowing easy transfer through small blood vessels range from about 0.5 to 10 μm; with larger bubbles, there are risks of clots and consecutive emboly. For instance, in the bubble suspensions disclosed in US-A-4,466,442 (Schering) in which aqueous solutions of surfactants such as lecithin, esters and ethers of fatty acids and fatty alcohols with polyoxyethylene and polyoxyethylated polyols like sorbitol, glycols and glycerol, cholesterol, or polyoxyethylene-polyoxypropylene polymers, are vigorously shaken with solutions of viscosity raising and stabilizing compounds such as mono- and polysaccharides (glucose, lactose, sucrose, dextran, sorbitol); polyols, e.g. glycerol, polyglycols; and polypeptides like proteins, gelatin, oxypolygelatin and plasma protein, only about 50% of the microbubbles are below 40-50 μm which makes such suspensions unsuitable in many echographic application.

**[0009]** In contrast, microcapsules or microballoons have been developed in an attempt to cure some or the foregoing deficiencies. As said before, while the microbubbles only have an immaterial or evanescent envelope, i.e. they are only surrounded by a wall of liquid whose surface tension is being modified by the presence of a surfactant, the microballoons or microcapsules have a tangible envelope made of substantive material other than the carrier itself, e.g. a polymeric membrane with definite mechanical strength. In other terms, they are microspheres of solid material in which the air or gas is more or less tightly encapsulated.

**[0010]** For instance, US-A-4,276,885 (Tickner et al.) discloses using surface membrane microcapsules containing a gas for enhancing ultrasonic images, the membrane including a multiplicity of non-toxic and non-antigenic organic molecules. In a disclosed embodiment, these microbubbles have a gelatin membrane which resists coalescence and their preferred size is 5-10 μm. The membrane of these microbubbles is said to be sufficiently stable for making echographic measurements; however it is also said that after a period of time the gas entrapped therein will dissolve in the blood-stream and the bubbles will gradually disappear, this being probably due to slow dissolution of the gelatin. Before use, the microcapsules are kept in gelatin solutions in which they are storage stable, but the gelatin needs to be heated and melted to become liquid at the time the suspension is used for making injection.

**[0011]** Microspheres of improved storage stability although without gelatin are disclosed in US-A-4,718,433 (Feinstein). These microspheres are made by sonication (5 to 30 KHz) of viscous protein solutions like 5% serum albumin and have diameters in the 2-20 μm range, mainly 2-4 μm. The microspheres are stabilized by denaturation of the membrane forming protein after sonication, for instance by using heat or by chemical means, e.g. by reaction with formaldehyde or glutaraldehyde. The concentration of stable microspheres obtained by this technique is said to be about $8 \times 10^6$/ml in the 2-4 μm range, about $10^6$/ml in the 4-5 μm range and less than $5 \times 10^5$ in the 5-6 μm range. The stability time of these microspheres is said to be 48 hrs or longer and they permit convenient left heart imaging after intravenous injection. For instance, the sonicated albumin microbubbles when injected into a peripheral vein are capable of transpulmonary passage. This results in echocardiographic opacification of the left ventricle cavity as well as myocardial tissues.

**[0012]** Recently still further improved microballoons for injection ultrasonic echography have been reported in EP-A-324.938 (Widder). In this document there are disclosed high concentrations (more than $10^8$) or air-filled protein-bounded microspheres of less than 10 μm which have life-times of several months or more. Aqueous suspensions of these microballoons are produced by ultrasonic cavitation of solutions of denaturable proteins, e.g. human serum albumin, which operation also leads to a degree of foaming of the membrane-forming protein and its subsequent hardening by heat. Other proteins such as hemoglobin and collagen are said to be convenient also.

**[0013]** Still more recently M.A. Wheatley et al., Biomaterials 11 (1990), 713-717, have reported the preparation of polymer-coated microspheres by ionotropic gelation of alginate. The reference mentions several techniques to generate the microcapsules; in one case an alginate solution was forced through a needle in an air jet which produced a spray of nascent air filled capsules which were hardened in a bath of 1.2% aqueous $CaCl_2$. In a second case involving co-extrusion of gas and liquid, gas bubbles were introduced into nascent capsules by means of a triple-barelled head, i.e. air was injected into a central capillary tube while an alginate solution was forced through a larger tube arranged coaxially with the capillary tube, and sterile air was flown around it through a mantle surrounding the second tube. Also in a third case, gas was trapped in the alginate solution before spraying either by using a homogeneizer or by sonication. The microballoons thus obtained had diameters in the range 30-100 μm, however still oversized for easily passing through lung capillaries.

**[0014]** The high storage stability of the suspensions of microballoons disclosed in EP-A-324.938 enables them to be marketed as such, i.e. with the liquid carrier phase, which is a strong commercial asset since preparation before use is no longer necessary. However, the protein material used in this document may cause allergenic reactions with sensitive patients and, moreover, the extreme strength and stability of the membrane material has some drawbacks: for instance, because of their rigidity, the membranes cannot sustain sudden pressure variations to which the microspheres can be subjected, for instance during travel through the blood-stream, these variations of pressure being due to heart pulsations. Thus, under practical ultrasonic tests, a proportion of the microspheres will be ruptured which makes imaging reproducibility awkward; also, these microballoons are not suitable for oral application as they will not

resist the digestive enzymes present in the gastrointestinal tract. Moreover, it is known that microspheres with flexible walls are more echogenic than corresponding microspheres with rigid walls.

**[0015]** Furthermore, in the case of injections, excessive stability of the material forming the walls of the microspheres will slow down its biodegradation by the organism under test and may result into metabolization problems. Hence it is much preferable to develop pressure sustaining microballoons bounded by a soft and elastic membrane which can temporarily deform under variations of pressure and endowed with enhanced echogenicity; also it might be visualized that micro-balloons with controllable biodegradability, for instance made of semi-permeable biodegradable polymers with controlled micro-porosity for allowing slow penetration of biological liquids, would be highly advantageous.

**[0016]** These desirable features have now been achieved with the microballoons of the present invention as defined in claims 1 and 2, and subsequent claims. Moreover, although the present microspheres can generally be made relatively short-lived, i.e. susceptible to biodegradation to cope with the foregoing metabolization problems by using selected types of polymers, this feature (which is actually controlled by the fabrication parameters) is not a commercial drawback because either the micro-balloons can be stored and shipped dry, a condition in which they are stable indefinitely, or the membrane can be made substantially impervious to the carrier liquid, degradation starting to occur only after injection. In the first case, the microballoons supplied in dry powder form are simply admixed with a proportion of an aqueous phase carrier before use, this proportion being selected depending on the needs. Note that this is an additional advantage over the prior art products because the concentration can be chosen at will and initial values far exceeding the aforementioned $10^8$/ml, i.e. in the range $10^5$ to $10^{10}$, are readily accessible. It should be noted that the method of the invention (to be disclosed hereafter) enables to control porosity to a wide extent; hence microballoons with a substantially impervious membrane can be made easily which are stable in the form of suspensions in aqueous liquids and which can be marketed as such also.

**[0017]** Microspheres with membranes of interfacially deposited polymers as defined in claim 1, although in the state where they are filled with liquid, are well known in the art. They may normally result from the emulsification into droplets (the size of which is controllable in function to the emulsification parameters) of a first aqueous phase in an organic solution of polymer followed by dispersion of this emulsion into a second water phase and subsequent evaporation of the organic solvent. During evaporation of the volatile solvent, the polymer deposits interfacially at the droplets boundary and forms a microporous membrane which efficiently bounds the encapsulated first aqueous phase from the surrounding second aqueous phase. This technique, although possible, is not preferred in the present invention.

**[0018]** Alternatively, one may emulsify with an emulsifier a hydrophobic phase in an aqueous phase (usually containing viscosity increasing agents as emulsion stabilizers) thus obtaining an oil-in-water type emulsion of droplets of the hydrophobic phase and thereafter adding thereto a membrane forming polymer dissolved in a volatile organic solvent not miscible with the aqueous phase.

**[0019]** If the polymer is insoluble in the hydrophobic phase, it will deposit interfacially at the boundary between the droplets and the aqueous phase. Otherwise, evaporation of the volatile solvent will lead to the formation of said interfacially deposited membrane around the droplets of the emulsified hydrophobic phase. Subsequent evaporation of the encapsulated volatile hydrophobic phase provides water filled microspheres surrounded by interfacially deposited polymer membranes. This technique which is advantageously used in the present invention is disclosed by K. Uno et al. in J. Microencapsulation 1 (1984), 3-8 and K. Makino et al., Chem. Pharm. Bull. 33 (1984), 1195-1201. As said before, the size of the droplets can be controlled by changing the emulsification parameters, i.e. nature of emulsifier (more effective the surfactant, i.e. the larger the hydrophilic to lipophilic balance, the smaller the droplets) and the stirring conditions (faster and more energetic the agitation, the smaller the droplets).

**[0020]** In another variant, the interfacial wall forming polymer is dissolved in the starting hydrophobic phase itself; the latter is emulsified into droplets in the aqueous phase and the membrane around the droplets will form upon subsequent evaporation of this encapsulated hydrophobic phase. An example of this is reported by J.R. Farnand et al., Powder Technology 22 (1978), 11-16 who emulsify a solution of polymer (e.g. polyethylene) in naphthalene in boiling water, then after cooling they recover the naphthalene in the form of a suspension of polymer bounded microbeads in cold water and, finally, they remove the naphthalene by subjecting the microbeads to sublimation, whereby 25 µm micro-balloons are produced. Other examples exist, in which a polymer is dissolved in a mixed hydrophobic phase comprising a volatile hydrophobic organic solvent and a water-soluble organic solvent, then this polymer solution is emulsified in a water phase containing an emulsifier, whereby the water-soluble solvent disperses into the water phase, thus aiding in the formation of the emulsion of micro-droplets of the hydrophobic phase and causing the polymer to precipitate at the interface; this is disclosed in EP-A-274.961 (H. Fessi).

**[0021]** The aforementioned techniques can be adapted to the preparation of air or gas filled microballoons suited for ultrasonic imaging provided that appropriate conditions are found to control sphere size in the desired ranges, cell-wall permeability or imperviousness and replacement of the encapsulated liquid phase by air or a selected gas. Control of overall sphere size is obviously important to adapt the microballoons to use purposes, i.e. injection or oral intake. The size conditions for injection (about 0.5 - 10 µm average size) have been discussed previously. For oral application, the range can be much wider, being considered that echogenicity increases with size; hence microballoons in several

size ranges between say 1 and 1000 μm can be used depending on the needs and provided the membrane is elastic enough not to break during transit in the stomach and intestine. Control of cell-wall permeability is important to ensure that infiltration by the injectable aqueous carrier phase is absent or slow enough not to impair the echographic measurements but, in cases, still substantial to ensure relatively fast after-test biodegradability, i.e. ready metabolization of the suspension by the organism. Also the microporous structure of the microballoons envelope (pores of a few nm to a few hundreds of nm or more for microballoons envelopes of thickness ranging from 50-500 nm) is a factor of resiliency, i.e. the microspheres can readily accept pressure variations without breaking. The preferred range of pore sizes is about 50-2000 nm.

**[0022]** The conditions for achieving these results are met by using the method disclosed in claims 17, 18 and subsequent claims.

**[0023]** One factor which enables to control the permeability of the microballoons membrane is the rate of evaporation of the hydrophobic phase relative to that of water in step (4) of the method of claim 17, e.g. under conditions of freeze drying which is the case of the embodiment recited in claim 20. For instance if the evaporation is carried out between about -40 and 0°C, and hexane is used as the hydrophobic phase, polystyrene being the interfacially deposited polymer, beads with relatively large pores are obtained; this is so because the vapour pressure of the hydrocarbon in the chosen temperature range is significantly greater than that of water, which means that the pressure difference between the inside and outside of the spheres will tend to increase the size of the pores in the spheres membrane through which the inside material will be evaporated. In contrast, using cyclooctane as the hydrophobic phase (at -17°C the vapour pressure is the same as that of water) will provide beads with very tiny pores because the difference of pressures between the inside and outside of the spheres during evaporation is minimized.

**[0024]** Depending on degree of porosity the microballoons of this invention can be made stable in an aqueous carrier from several hours to several months and give reproducible echographic signals for a long period of time. Actually, depending on the polymer selected, the membrane of the micro-balloons can be made substantially impervious when suspended in carrier liquids of appropriate osmotic properties, i.e. containing solutes in appropriate concentrations. It should be noted that the existence of micropores in the envelope of the microballoons of the present invention appears to be also related with the echographic response, i.e., all other factors being constant, microporous vesicles provide more efficient echographic signal than corresponding non-porous vesicles. The reason is not known but it can be postulated that when a gas is in resonance in a closed structure, the damping properties of the latter may be different if it is porous or non-porous.

**[0025]** Other non water soluble organic solvents which have a vapour pressure of the same order of magnitude between about -40°C and 0°C are convenient as hydrophobic solvents in this invention. These include hydrocarbons such as for instance n-octane, cyclooctane, the dimethylcyclohexanes, ethyl-cyclohexane, 2-, 3- and 4-methyl-heptane, 3-ethyl-hexane, toluene, xylene, 2-methyl-2-heptane, 2,2,3,3-tetramethylbutane and the like. Esters such as propyl and isopropyl butyrate and isobutyrate, butyl-formate and the like, are also convenient in this range. Another advantage of freeze drying is to operate under reduced pressure of a gas instead of air, whereby gas filled microballoons will result. Physiologically acceptable gases such as $CO_2$, $N_2O$, methane, Freon, helium and other rare gases are possible. Gases with radioactive tracer activity can be contemplated.

**[0026]** As the volatile solvent insoluble in water to be used for dissolving the polymer to be precipitated interfacially, one can cite halo-compounds such as $CCl_4$, $CH_3Br$, $CH_2Cl_2$, chloroform, Freon, low boiling esters such as methyl, ethyl and propyl acetate as well as lower ethers and ketones of low water solubility. When solvents not totally insoluble in water are used, e.g. diethyl-ether, it is advantageous to use, as the aqueous phase, a water solution saturated with said solvent beforehand.

**[0027]** The aqueous phase in which the hydrophobic phase is emulsified as an oil-in-water emulsion preferably contains 1-20% by weight of water-soluble hydrophilic compounds like sugars and polymers as stabilizers, e.g. polyvinyl alcohol (PVA), polyvinyl pyrrolidone (PVP), polyethylene glycol (PEG), gelatin, polyglutamic acid, albumin, and polysaccharides such as starch, dextran, agar, xan-than and the like. Similar aqueous phases can be used as the carrier liquid in which the microballoons are suspended before use.

**[0028]** Part of this water-soluble polymer can remain in the envelope of the microballoons or it can be removed by washing the beads before subjecting them to final evaporation of the encapsulated hydrophobic core phase.

**[0029]** The emulsifiers to be used (0.1-5% by weight) to provide the oil-in-water emulsion of the hydrophobic phase in the aqueous phase include most physiologically acceptable emulsifiers, for instance egg lecithin or soya bean lecithin, or synthetic lecithins such as saturated synthetic lecithins, for example, dimyristoyl phosphatidyl choline, dipalmitoyl phosphatidyl choline or distearoyl phosphatidyl choline or unsaturated synthetic lecithins, such as dioleyl phosphatidyl choline or dilinoleyl phosphatidyl choline. Emulsifiers also include surfactants such as free fatty acids, esters of fatty acids with polyoxyalkylene compounds like polyoxypropylene glycol and polyoxyethylene glycol; ethers of fatty alcohols with polyoxyalkylene glycols; esters of fatty acids with polyoxyalkylated sorbitan; soaps; glycerol-polyalkylene stearate; glycerol-polyoxyethylene ricinoleate; homo- and copolymers of polyalkylene glycols; polyethoxylated soya-oil and castor oil as well as hydrogenated derivatives; ethers and esters of sucrose or other carbohydrates with fatty acids, fatty

alcohols, these being optionally polyoxyalkylated; mono-, di- and triglycerides of saturated or unsaturated fatty acids; glycerides or soya-oil and sucrose.

**[0030]** The polymer which constitutes the envelope or bounding membrane of the injectable microballoons can be selected from most hydrophilic, biodegradable physiologically compatible polymers. Among such polymers one can cite polysaccharides of low water solubility, polylactides and polyglycolides and their copolymers, copolymers of lactides and lactones such as ε-caprolactone,-valerolactone and polypeptides. The great versatility in the selection of synthetic polymers is another advantage of the present invention since, as with allergic patients, one may wish to avoid using microballoons made of natural proteins (albumin, gelatin) like in US-A-4,276,885 or EP-A-324.938. Other suitable polymers include poly-(ortho)esters (see for instance US-A-4,093,709; US-A-4,131,648; US-A-4,138,344; US-A-4,180,646); polylactic and polyglycolic acid and their copolymers, for instance DEXON (see J. Heller, Biomaterials 1 (1980), 51; poly(DL-lactide-co-∂-caprolactone),poly(DL-lactide-co-∂-valerolactone), poly(DL-lactide-co-γ-butyrolactone), polyalkylcyanoacrylates; polyamides, polyhydroxybutyrate; polydioxanone; poly-β-aminoketones (Polymer 23 (1982), 1693); polyphosphazenes (Science 193 (1976), 1214); and polyanhydrides. References on biodegradable polymers can be found in R. Langer et al., Macromol. Chem. Phys. C23 (1983), 61-126. Polyamino-acids such as polyglutamic and polyaspartic acids can also be used as well as their derivatives, i.e. partial esters with lower alcohols or glycols. One useful example of such polymers is poly-(t.butyl-glutamate). Copolymers with other amino-acids such as methionine, leucine, valine, proline, glycine, alamine, etc. are also possible. Recently some novel derivatives of polyglutamic and polyaspartic acid with controlled biodegradability have been reported (see WO87/03891; US 4,888,398 and EP-130.935). These polymers (and copolymers with other amino-acids) have formulae of the following type:

$$-(NH\text{-}CHA\text{-}CO)_x(NH\text{-}CHX\text{-}CO)_y$$

where X designates the side chain of an aminoacid residue and A is a group of formula $-(CH_2)_n COOCR^1R^2\text{-}OCOR$ (II), with $R^1$ and $R^2$ being H or lower alkyls, and R being alkyl or aryl; or R and $R^1$ are connected together by a substituted or unsubstituted linking member to provide 5- or 6- membered rings.

**[0031]** A can also represent groups of formulae:

$$-(CH_2)_n COO\text{-}CHR^1COOR \qquad (I)$$

and

$$-(CH_2)_n CO(NH\text{-}CHX\text{-}CO)_m NH\text{-}CH(COOH)\text{-}(CH_2)_p COOH \qquad (III)$$

and corresponding anhydrides. In all these formulae n, m and p are lower integers (not exceeding 5) and x and y are also integers selected for having molecular weights not below 5000.

**[0032]** The aforementioned polymers are suitable for making the microballoons according to the invention and, depending on the nature of substituents R, $R^1$, $R^2$ and X, the properties of the membrane can be controlled, for instance, strength, elasticity and biodegradability. For instance X can be methyl (alanine), isopropyl (valine), isobutyl (leucine and isoleucine), benzyl (phenylalanine).

**[0033]** Additives can be incorporated into the polymer wall of the microballoons to modify the physical properties such as dispersibility, elasticity and water permeability. For incorporation in the polymer, the additives can be dissolved in the polymer carrying phase, e.g. the hydrophobic phase to be emulsified in the water phase, whereby they will co-precipitate with the polymer during inter-facial membrane formation.

**[0034]** Among the useful additives, one may cite compounds which can "hydrophobize" the microballoons membrane in order to decrease water permeability, such as fats, waxes and high molecular-weight hydrocarbons. Additives which improve dispersibility of the microballoons in the injectable liquid-carrier are amphipatic compounds like the phospholipids; they also increase water permeability and rate of biodegradability.

**[0035]** Non-biodegradable polymers for making micro-balloons to be used in the digestive tract can be selected from most water-insoluble, physiologically acceptable, bioresistant polymers including polyolefins (polystyrene), acrylic resins (polyacrylates, polyacrylonitrile), polyesters (polycarbonate), polyurethanes, polyurea and their copolymers. ABS (acryl-butadiene-styrene) is a preferred copolymer.

**[0036]** Additives which increase membrane elasticity are the plasticizers like isopropyl myristate and the like. Also, very useful additives are constituted by polymers akin to that of the membrane itself but with relatively low molecular

weight. For instance when using copolymers of polylactic/polyglycolic type as the membrane forming material, the properties of the membrane can be modified advantageously (enhanced softness and biodegradability) by incorporating, as additives, low molecular weight (1000 to 15,000 Dalton) polyglycolides or polylactides. Also polyethylene glycol of moderate to low $M_w$ (e.g. PEG 2000) is a useful softening additive.

**[0037]** The quantity of additives to be incorporated in the polymer forming the inter-facially deposited membrane of the present microballoons is extremely variable and depends on the needs. In some cases no additive is used at all; in other cases amounts of additives which may reach about 20% by weight of the polymer are possible.

**[0038]** The injectable microballoons of the present invention can be stored dry in the presence or in the absence of additives to improve conservation and prevent coalescence. As additives, one may select from 0.1 to 25% by weight of water-soluble physiologically acceptable compounds such as mannitol, galactose, lactose or sucrose or hydrophilic polymers like dextran, xanthan, agar, starch, PVP, polyglutamic acid, polyvinylalcohol (PVA), albumin and gelatin. The useful life-time of the microballoons in the injectable liquid carrier phase, i.e. the period during which useful echographic signals are observed, can be controlled to last from a few minutes to several months depending on the needs; this can be done by controlling the porosity of the membrane from substantial imperviousness toward carrier liquids to porosities having pores of a few nanometers to several hundreds of nanometers. This degree of porosity can be controlled, in addition to properly selecting the membrane forming polymer and polymer additives, by adjusting the evaporation rate and temperature in step (4) of the method of claim 17 and properly selecting the nature of the compound (or mixture of compounds) constituting the hydrophobic phase, i.e. the greater the differences in its partial pressure of evaporation with that of the water phase, the coarser the pores in the microballoons membrane will be. Of course, this control by selection of the hydrophobic phase can be further refined by the choice of stabilizers and by adjusting the concentration thereof in order to control the rate of water evaporation during the forming of the micro-balloons. All these changes can easily be made by skilled ones without exercizing inventiveness and need not be further discussed.

**[0039]** It should be remarked that although the micro-balloons of this invention can be marketed in the dry state, more particularly when they are designed with a limited life time after injection, it may be desirable to also sell ready preparations, i.e. suspensions of microballoons in an aqueous liquid carrier ready for injection or oral administration. This requires that the membrane of the microballoons be substantially impervious (at least for several months or more) to the carrier liquid. It has been shown in this description that such conditions can be easily achieved with the present method by properly selecting the nature of the polymer and the interfacial deposition parameters. Actually parameters have been found (for instance using the polyglutamic polymer (where A is the group of formula II) and cyclooctane as the hydrophobic phase) such that the porosity of the membrane after evaporation of the hydrophobic phase is so tenuous that the microballoons are substantially impervious to the aqueous carrier liquid in which they are suspended.

**[0040]** A preferred administrable preparation for diagnostic purposes comprises a suspension in buffered or unbuffered saline (0.9% aqueous NaCl; buffer 10 mM tris-HCl) containing $10^8$-$10^{10}$ vesicles/ml. This can be prepared mainly according to the directions of the Examples below, preferably Examples 3 and 4, using poly-(DL-lactide) polymers from the Company Boehringer, Ingelheim, Germany.

**[0041]** The following Examples illustrate the invention practically.

Example 1

**[0042]** One gram of polystyrene was dissolved in 19 g of liquid naphthalene at 100°C. This naphthalene solution was emulsified at 90-95 ° C into 200 ml of a water solution of polyvinyl alcohol (PVA) (4% by weight) containing 0.1% of Tween-40 emulsifier. The emulsifying head was a Polytron PT-3000 at about 10,000 rpm. Then the emulsion was diluted under agitation with 500 ml of the same aqueous phase at 15°C whereby the naphthalene droplets solidified into beads of less than 50 µm as ascertained by passing through a 50 µm mesh screen. The suspension was centrifugated under 1000 g and the beads were washed with water and recentrifugated. This step was repeated twice.

**[0043]** The beads were resuspended in 100 ml of water with 0.8 g of dissolved lactose and the suspension was frozen into a block at 30 ° C. The block was thereafter evaporated under about 67-133.3 $Nt/m^2$ (0.5-2 Torr) between about -20 and -10°C. Air filled microballoons of average size 5-10 µm and controlled porosity were thus obtained which gave an echographic signal at 2.25 and 7.5 MHz after being dispersed in water (3% dispersion by weight). The stability of the microballoons in the dry state was effective for an indefinite period of time; once suspended in an aqueous carrier liquid the useful life-time for echography was about 30 min or more. Polystyrene being non-biodegradable, this material was not favored for injection echography but was useful for digestive tract investigations. This Example clearly establishes the feasibility of the method of the invention.

Example 2

**[0044]** A 50:50 copolymer mixture (0.3 g) of DL-lactide and glycolide (Du Pont Medisorb) and 16 mg of egg-lecithin were dissolved in 7.5 ml of $CHCl_3$ to give solution (1).

**[0045]** A solution (2) containing 20 mg of paraffin-wax (M.P. 54-56°C) in 10 ml of cyclooctane (M.P. 10-13 °) was prepared and emulsified in 150 ml of a water solution (0.13% by weight) of Pluronic F-108 (a block copolymer of ethylene oxide and propylene oxide) containing also 1.2 g of $CHCl_3$. Emulsification was carried out at room temperature for 1 min with a Polytron head at 7000 rpm. Then solution (1) was added under agitation (7000 rpm) and, after about 30- 60 sec, the emulsifier head was replaced by a helical agitator (500 rpm) and stirring was continued for about 3 hrs at room temperature (22°C). The suspension was passed through a 50 µm screen and frozen to a block which was subsequently evaporated between -20 and 0°C under high-vacuum (catching trap -60 to -80°C). There were thus obtained 0.264 g (88%) of air-filled microballoons stable in the dry state.

**[0046]** Suspensions of said microballoons in water (no stabilizers) gave a strong echographic signal for at least one hour. After injection in the organism, they biodegraded in a few days.

Example 3

**[0047]** A solution was made using 200 ml of tetrahydrofuran (THF), 0.8 g of a 50:50 DL-lactide/glycolide copolymer (Boehringer AG), 80 mg of egg-lecithin, 64 mg of paraffin-wax and 4 ml of octane. This solution was emulsified by adding slowly into 400 ml of a 0.1% aqueous solution of Pluronic F-108 under helical agitation (500 r.p.m.). After stirring for 15 min, the milky dispersion was evaporated under 1333-1600 $Nt/m^2$ (10-12 Torr) 25°C in a rotavapor until its volume was reduced to about 400 ml. The dispersion was sieved on a 50 µm grating, then it was frozen to -40°C and freeze-dried under about 133.3 $Nt/m^2$ (1 Torr). The residue, 1.32 g of very fine powder, was taken with 40 ml of distilled water which provided, after 3 min of manual agitation, a very homogeneous dispersion of microballoons of average size 4.5 µm as measured using a particle analyzer (Mastersizer from Malvern). The concentration of microballoons (Coulter Counter) was about $2 \times 10^9$/ml . This suspension gave strong echographic signals which persisted for about 1 hr. If in the present example, the additives to the membrane polymer are omitted, i.e. there is used only 800 mg of the lactide/glycolide copolymer in the THF/octane solution, a dramatic decrease in cell-wall permeability is observed, the echographic signal of the dispersion in the aqueous carrier not being significantly attenuated after 3 days.

**[0048]** Using intermediate quantities of additives provided beads with controlled intermediate porosity and life-time.

Example 4

**[0049]** There was used in this Example a polymer of formula defined in claim 8 in which the side group has formula (II) where $R^1$ and $R^2$ are hydrogen and R is tert.butyl. The preparation of this polymer (defined as poly-POMEG) is described in US-A-4,888,398.

**[0050]** The procedure was like in Example 3, using 0.1 g poly-POMEG, 70 ml of THF, 1 ml of cyclooctane and 100 ml of a 0.1% aqueous solution of Pluronic F-108. No lecithin or high-molecular weight hydrocarbon was added. The milky emulsion was evaporated at 27°C/ 1333 $Nt/m^2$ (10 Torr) until the residue was about 100 ml, then it was screened on a 50 µm mesh and frozen. Evaporation of the frozen block was carried out 67-133.3 $Nt/m^2$ (0.5-1 Torr) until dry. The yield was 0.18 g because of the presence of the surfactant . This was dispersed in 10 ml of distilled water and counted with a Coulter Counter. The measured concentration was found to be $1,43 \times 10^9$ microcapsules/ml, average size 5.21 µm as determined with a particle analyzer (Mastersizer from Malvern). The dispersion was diluted 100 x, i. e. to give about $1.5 \times 10^7$ microspheres/ml and measured for echogenicity. The amplitude of the echo signal was 5 times greater at 7.5 MHz than at 2.25 MHz. These signals were reproducible for a long period of time.

**[0051]** Echogenicity measurements were performed with a pulse-echo system consisting of a plexiglas specimen holder (diameter 30 mm) with a 20 µm thick Mylar acoustic window, a transducer holder immersed in a constant temperature water bath, a pulser-receiver (Accutron M3010JS) with an external pre-amplifier with a fixed gain of 40 dB and an internal amplifier, with gain adjustable from -40 to +40 dB and interchangeable 13 mm unfocused transducers. A 10 MHz low-pass filter was inserted in the receiving part to improve the signal to noise ratio. The A/D board in the IBM PC was a Sonotek STR 832. Measurements were carried out at 2.25, 3.5, 5 and 7.5 MHz.

**[0052]** If in the present Example, the polymer used is replaced by lactic-lactone copolymers, the lactones being γ-butyrolactone, ∂-valerolactone or ε-caprolactone (see Fukuzaki et al., J. Biomedical Mater. Res. 25 (1991), 315-328), similar favorable results were obtained. Also in a similar context, polyalkylcyanoacrylates and particularly a 90:10 copolymer poly(DL-lactide-coglycolide) gave satisfactory results. Finally, a preferred polymer is a poly(DL-lactide) from the Company Boehringer-In-gelheim sold under the name "Resomer R-206"or Resomer R-207.

Example 5

**[0053]** Two-dimensional echocardiography was performed using an Acuson-128 apparatus with the preparation of Example 4 ($1.43 \times 10^9$/ml) in an experimental dog following peripheral vein injection of 0.1-2 ml of the dispersion. After normally expected contrast enhancement imaging of the right heart, intense and persistent signal enhancement of the

left heart with clear outlining of the endocardium was observed, thereby confirming that the microballoons made with poly-POMEG (or at least a significant part of them) were able to cross the pulmonary capillary circulation and to remain in the blood-stream for a time sufficient to perform efficient echographic analysis.

**[0054]** In another series of experiments, persistent enhancement of the Doppler signal from systemic arteries and the portal vein was observed in the rabbit and in the rat following peripheral vein injection of 0.5-2 ml of a preparation of microballoons prepared as disclosed in Example 4 but using poly-(DL-lactic acid) as the polymer phase. The composition used contained $1.9 \times 10^8$ vesicles/ml.

**[0055]** Another composition prepared also according to the directions of Example 4 was achieved using poly(tert. butylglutamate). This composition (0.5 ml) at dilution of $3.4 \times 10^6$ microballoons/ml was injected in the portal vein of rats and gave persistent contrast enhancement of the liver parenchyma.

Example 6

**[0056]** A microballoon suspension ($1.1 \times 10^9$ vesicles/ml) was prepared as disclosed in Example 1 (resin = polystyrene). One ml of this suspension was diluted with 100 ml of 300 mM mannitol solution and 7 ml of the resulting dilution was administered intragastrically to a laboratory rat. The animal was examined with an Acuson-128 apparatus for 2-dimensional echography imaging of the digestive tract which clearly showed the single loops of the small intestine and of the colon.

**Claims**

1. Microballoons of micronic or submicronic size comprising a polymer membrane filled with air or gas, said microballoons being suitable, when in the form of suspensions in a liquid carrier, for administration to human or animal patients for therapeutic or diagnostic applications including echography imaging, **characterized in that** the membrane polymer is a synthetic, deformable, resilient and interfacially depositable polymer, obtainable by the steps of:

   (1) emulsifying a hydrophobic organic phase into a water phase so as to obtain droplets of said hydrophobic phase as an oil-in-water emulsion in said water phase;

   (2) adding to said emulsion a solution of at least one polymer in a volatile solvent insoluble in the water phase, so that a layer of said polymer will form around said droplets;

   (3) evaporating said volatile solvent so that the polymer will deposit by interfacial precipitation around the droplets which then form beads with a core of said hydrophobic phase encapsulated by a membrane of said polymer, said beads being in suspension in said water phase;

   (4) subjecting said suspension to freeze drying conditions; wherein said hydrophobic phase is selected so that it evaporates substantially simultaneously with the water phase and is replaced by air or gas, whereby dry, free flowing, readily dispersible microballoons are obtained;

   (5) wherein said polymer may be dissolved in said hydrophobic phase, so that steps (2) and (3) can be omitted and the polymer membrane will form by interfacial precipitation during step (4).

2. The microballoons of claim 1, having size mostly in the 0.5 - 10 μm range suitable for injection into the blood-stream of living beings. in which the membrane is either impervious or permeable to bioactive liquids for increasing the rate of biodegradation.

3. The microballoons of claim 2, in which the polymer membrane is porous and has porosity ranging from a few nanometers to several thousands of nanometers, preferably 50-2,000 nm.

4. The microballoons of claim 2, in which the membrane is elastic, has a thickness of 50-500 nm, and resists pressure variations produced by heart beat pulsations in the blood-stream.

5. The microballoons of claims 1, in which the polymer of the membrane is a biodegradable polymer selected from polysaccharides, polyamino-acids, polylactides and polyglycolides and their copolymers, copolymers of lactides and lactones, polypeptides, poly-(ortho)esters, polydioxanone, poly-β-aminoketones, polyphosphazenes, polyanhydrides and polyalkyl-(cyano)acrylates.

6. The microballoons of claims 1, wherein the membrane polymer is selected from polyglutamic or polyaspartic acid derivatives and their copolymers with other amino-acids.

7. The microballoons of claim 6, wherein the polyglutamic and polyaspartic acid derivatives are selected from esters and amides involving the carboxylated side function thereof, said side functions having formulae

$$(CH_2)_nCOO\text{-}CHR^1COOR \quad (I),$$

or

$$(CH_2)_nCOOCR^1R^2\text{-}O\text{-}COR \quad (II),$$

or

$$(CH_2)_nCO(NH\text{-}CHX\text{-}CO)_mNHCH(COOH)\text{-}(CH_2)\text{-}_pCOOH \quad (III),$$

wherein R is an alkyl or aryl substituent; $R^1$ and $R^2$ are H or lower alkyls, or R and $R^1$ are connected together by a substituted or unsubstituted linking member to form a 5- or 6- membered ring; n is 1 or 2; p is 1, 2 or 3; m is an integer from 1 to 5 and X is a side chain of an aminoacid residue.

8. The microballoons of claims 1, wherein the membrane polymer contains additives to control the degree of elasticity, and the size and density of the pores for permeability control.

9. The microballoons of claim 8, wherein said additives include plasticizers. amphipatic substances and hydrophobic compounds.

10. The microballoons of claim 9, wherein the plasticizers include isopropyl myristate. glyceryl monostearate and the like to control flexibility, the amphipatic substances include surfactants and phospholipids like the lecithins to control permeability by increasing porosity and the hydrophobic compounds include high molecular weight hydrocarbon like the paraffinwaxes to reduce porosity.

11. The microballoons of claim 9, wherein the additives include polymers of molecular weight in the range of 1,000 to 15,000 to control softness and resiliency of the microballoon membrane.

12. The microballoons of claim 11, wherein the low molecular weight polymer additives are selected from polylactides, polyglycolides. polyalkylene glycols like polyethylene glycol and polypropylene glycol, and polyols like polyglycerol.

13. The microballoons of claims 1, having size up to about 1000 µm suitable for oral, rectal and urethral applications, wherein the membrane polymer is not biodegradable in the digestive tract and impervious to biological liquids.

14. The microballoons of claim 14, wherein the polymer is selected from polyolefins, polyacrylates, polyacrylonitrile, non-hydrolyzable polyesters, polyurethanes and polyureas.

15. An injectable aqueous suspension of microballoons according to claims 1 - 14, **characterized in that** the microballoons are present in a concentration of about $10^6$ to $10^{10}$ microballoons/ml, said suspension being stable for at least thirty days.

16. The injectable aqueous suspension of claim 15, wherein the microballoons are bounded by a membrane of interfacially precipitated DL-lactide polymer defined by the commercial name of Resomer.

17. A method for making air or gas filled microballoons usable as suspensions in a carrier liquid for oral, rectal and urethral applications, or for injections into living organisms, this method **characterized by** the steps of:

(1) emulsifying a hydrophobic organic phase into a water phase so as to obtain droplets of said hydrophobic

phase as an oil-in-water emulsion in said water phase;
(2) adding to said emulsion a solution of at least one polymer in a volatile solvent insoluble in the water phase, so that a layer of said polymer will form around said droplets;
(3) evaporating said volatile solvent so that the polymer will deposit by interfacial precipitation around the droplets which then form beads with a core of said hydrophobic phase encapsulated by a membrane of said polymer, said beads being in suspension in said water phase:
(4) subjecting said suspension to reduced pressure under conditions such that said encapsulated hydrophobic phase be removed by evaporation:

wherein said hydrophobic phase is selected so that it evaporates substantially simultaneously with the water phase and is replaced by air or gas, whereby dry, free flowing, readily dispersible microballoons are obtained.

18. The method of claim 17, wherein said polymer is dissolved in said hydrophobic phase, so that steps (2) and (3) can be omitted and the polymer membrane will form by interfacial precipitation during step (4).

19. The method of claim 17, wherein evaporation of said hydrophobic phase in step (4) is performed at a temperature where the partial vapour pressure of said hydrophobic phase is of the same order as that of water vapour.

20. The method of claim 17 wherein said evaporation of step (4) is carried out under freeze-drying conditions.

21. The method of claim 20, wherein freeze-drying is effected at temperatures of from -40°C to 0°C.

22. The method of claims 17 or 20, wherein the hydrophobic phase is selected from organic compounds having a vapour pressure of about 133.3 Nt/m$^2$ (1 Torr) at a temperature comprised in the interval of about -40° C to 0°C.

23. The method of claims 17 or 18, wherein the aqueous phase comprises, dissolved, from about 1 to 20% by weight of stabilizers comprising hydrophilic compound selected from sugars, PVA, PVP, gelatin, starch, dextran, polydextrose, albumin and the like.

24. The method of claim 18, wherein additives to control the degree of permeability of the microballoons membrane are added to the hydrophobic phase, the rate of biodegradability of the polymer after injecting the microballoons into living organisms being a function of said degree of permeability.

25. The method of claim 24, wherein the said additives include hydrophobic solids like fats, waxes and high molecular weight hydrocarbons, the presence of which in the membrane polymer of the microballoons will reduce permeability toward aqueous liquids.

26. The method of claim 24, wherein the said additives include amphipatic compounds like the phospholipids, or low molecular weight polymers, the presence of which in the membrane polymer will increase permeability of the microballoons to aqueous liquids.

27. The method of claim 18, wherein the hydrophobic phase subjected to emulsification in said water phase also contains a water-soluble solvent which, upon being diluted into said water phase during emulsification, will aid in reducing the size of droplets and induce inter-facial precipitation of the polymer before step (4) is carried out.

28. Use of microballoons of claims 1-14 for ultrasonic echography imaging of human or animal body.

29. Use of microballoons of claims 1-14 for ultrasonic echography imaging of liver.

**Patentansprüche**

1. Mikroballone mikronischer oder submikronischer Größe enthaltend eine mit Luft oder Gas gefüllte Polymermembran, wobei die Mikroballone, wenn sie in Form von Suspensionen in einem Flüssigträger vorliegen, zur Verabreichung an menschliche oder tierische Patienten für therapeutische oder diagnostische Anwendungen einschließlich Abbildung durch Echographie geeignet sind, **dadurch gekennzeichnet, daß** das Membranpolymer ein synthetisches, verformbares, elastisches und grenzflächig ablagerbares Polymer ist, erhältlich durch die Schritte:

(1) Emulgieren einer hydrophoben organischen Phase in einer Wasserphase, um Tröpfchen der hydrophoben Phase als Öl-in-Wasser Emulsion in der Wasserphase zu erhalten;

(2) Zugeben einer Lösung von mindestens einem Polymer in einem flüchtigen, in der Wasserphase unlöslichen Lösungsmittel zu der Emulsion, so daß sich eine Schicht des Polymers um die Tröpfchen herum bildet;

(3) Verdampfen des flüchtigen Lösungsmittels, so daß sich das Polymer durch grenzflächige Abscheidung um die Tröpfchen herum ablagert, welche dann Kügelchen bilden mit einem Kern aus der hydrophoben Phase, der durch eine Membran des Polymers eingekapselt ist, wobei die Kügelchen in Suspension in der Wasserphase vorliegen;

(4) Unterwerfen der Suspension unter Gefriertrocknungsbedingungen, wobei die hydrophobe Phase so gewählt ist, daß sie im wesentlichen gleichzeitig mit der Wasserphase verdampft und durch Luft oder Gas ersetzt wird, wodurch trockene, freifließende, leicht dispergierbare Mikroballone erhalten werden;

(5) wobei das Polymer in der hydrophoben Phase gelöst sein kann, so daß die Schritte (2) und (3) weggelassen werden können und sich die Polymermembran in Schritt (4) durch grenzflächige Abscheidung bildet.

2. Mikroballone nach Anspruch 1, welche überwiegend eine zur Injektion in den Blutstrom von Lebewesen geeignete Größe im Bereich von 0,5 - 10 µm haben, in denen die Membran entweder undurchlässig oder zur Steigerung der Geschwindigkeit des Bioabbaus für bioaktive Flüssigkeiten permeabel ist.

3. Mikroballone nach Anspruch 2, in welchen die Polymermembran porös ist und eine Porosität im Bereich von einigen Nanometern bis zu mehreren tausend Nanometern, vorzugsweise 50-2000 nm, aufweist.

4. Mikroballone nach Anspruch 2, in welchen die Membran elastisch ist, eine Dicke von 50-500 nm aufweist, und Druckschwankungen standhält, die im Blutstrom durch Herzschlagpulsationen erzeugt werden.

5. Mikroballone nach Anspruch 1, in welchen das Polymer der Membran ein bioabbaubares Polymer ist, ausgewählt aus Polysacchariden, Polyaminosäuren, Polylactiden und Polyglykoliden und ihren Copolymeren, Copolymeren von Lactiden und Lactonen, Polypeptiden, Poly(ortho)estern, Polydioxanon, Poly-β-aminoketonen, Polyphosphazenen, Polyanhydriden und Polyalkyl(cyano)acrylaten.

6. Mikroballone nach Anspruch 1, in welchen das Membranpolymer aus Polyglutamin- oder Polyasparaginsäurederivaten und deren Copolymeren mit anderen Aminosäuren ausgewählt ist.

7. Mikroballone nach Anspruch 6, in welchen die Polyglutamin- und Polyasparaginsäurederivate aus Estern und Amiden ausgewählt sind, an denen die carboxylierte Seitenfunktion derselben beteiligt ist, wobei diese Seitenfunktionen die Formeln

$$(CH_2)_nCOO\text{-}CHR^1COOR \qquad (I),$$

oder

$$(CH_2)_nCOOCR^1R^2\text{-}O\text{-}COR \qquad (II),$$

oder

$$(CH_2)_nCO(NH\text{-}CHX\text{-}CO)_mNHCH(COOH)\text{-}(CH_2)_pCOOH \qquad (III)$$

haben, worin R ein Alkyl- oder Arylsubstituent ist; $R^1$ und $R^2$ H oder niedere Alkyle sind, oder R und $R^1$ durch ein substituiertes oder unsubstituiertes Verbindungsglied unter Bildung eines 5- oder 6-gliedrigen Rings miteinander verbunden sind; n für 1 oder 2 steht; p für 1, 2 oder 3 steht; m eine ganze Zahl von 1 bis 5 ist und X eine Seitenkette eines Aminosäurerestes ist.

8. Mikroballone nach Anspruch 1, in welchen das Membranpolymer Additive zum Kontrollieren des Elastizitätsgrades, und der Größe und Dichte der Poren zur Permeabilitätssteuerung enthält.

9. Mikroballone nach Anspruch 8, in welchen die Additive Weichmacher, amphiphatische Substanzen und hydrophobe Verbindungen umfassen.

10. Mikroballone nach Anspruch 9, in welchen die Weichmacher Isopropylmyristat, Glycerylmonostearat und dergleichen zum Steuern der Flexibilität umfassen, die amphiphatischen Substanzen oberflächenaktive Substanzen und Phospholipide wie die Lecithine zum Steuern der Permeabilität durch Steigern der Porosität umfassen und die hydrophoben Verbindungen Kohlenwasserstoff hohen Molekulargewichts wie die Paraffinwachse zur Verringerung der Porosität umfassen.

11. Mikroballone nach Anspruch 9, in welchen die Additive Polymere mit einem Molekulargewicht im Bereich von 1000 bis 15000 zur Steuerung der Weichheit und Elastizität der Mikroballonmembran umfassen.

12. Mikroballone nach Anspruch 11, in welchen die polymeren Additive niederen Molekulargewichts aus Polylactiden, Polyglykoliden, Polyalkylenglykolen, wie Polyethylenglykol und Polypropylenglykol, und Polyolen, wie Polyglycerin, ausgewählt sind.

13. Mikroballone nach Anspruch 1, welche eine für orale, rektale und urethrale Applikationen geeignete Größe bis zu etwa 1000 µm haben, in welchen das Membranpolymer im Verdauungstrakt nicht bioabbaubar und undurchlässig für biologische Flüssigkeiten ist.

14. Mikroballone nach Anspruch 13, in welchen das Polymer aus Polyolefinen, Polyacrylaten, Polyacrylnitril, nichthydrolysierbaren Polyestern, Polyurethanen und Polyharnstoffen ausgewählt ist.

15. Injizierbare wäßrige Suspension von Mikroballonen gemäß den Ansprüchen 1 bis 14, **dadurch gekennzeichnet, daß** die Mikroballone in einer Konzentration von etwa $10^6$ bis $10^{10}$ Mikroballonen/ml anwesend sind, wobei diese Suspension mindestens 30 Tage stabil ist.

16. Injizierbare wäßrige Suspension nach Anspruch 15, in welcher die Mikroballone durch eine Membran grenzflächig ausgefällten DL-Lactidpolymers, das durch den Handelsnamen Resomer definiert ist, begrenzt sind.

17. Verfahren zum Herstellen luft- oder gasgefülter Mikroballone, die als Suspensionen in einer Trägerflüssigkeit für orale, rektale und urethrale Applikationen oder für Injektionen in lebende Organismen anwendbar sind, **gekennzeichnet durch** die Schritte:

    (1) Emulgieren einer hydrophoben organischen Phase in einer Wasserphase, um Tröpfchen der hydrophoben Phase als Öl-in-Wasser Emulsion in der Wasserphase zu erhalten;

    (2) Zugeben einer Lösung von mindestens einem Polymer in einem flüchtigen, in der Wasserphase unlöslichen Lösungsmittel zu der Emulsion, so daß sich eine Schicht des Polymers um die Tröpfchen herum bildet;

    (3) Verdampfen des flüchtigen Lösungsmittels, so daß sich das Polymer durch grenzflächige Abscheidung um die Tröpfchen herum ablagert, welche dann Kügelchen bilden mit einem Kern aus der hydrophoben Phase, der durch eine Membran des Polymers eingekapselt ist, wobei die Kügelchen in Suspension in der Wasserphase vorliegen;

    (4) Setzen der Suspension unter verringerten Druck unter solchen Bedingungen, daß diese eingekapselte hydrophobe Phase durch Verdampfen entfernt wird;

    wobei die hydrophobe Phase so ausgewählt ist, daß sie im wesentlichen gleichzeitig mit der Wasserphase verdampft und durch Luft oder Gas ersetzt wird, wodurch trockene, freifließende, leicht dispergierbare Mikroballone erhalten werden.

18. Verfahren nach Anspruch 17, in welchem das Polymer in der hydrophoben Phase gelöst ist, so daß die Schritte (2) und (3) weggelassen werden können und sich die Polymermembran in Schritt (4) durch grenzflächige Abscheidung bildet.

19. Verfahren nach Anspruch 17, in welchem die Verdampfung der hydrophoben Phase in Schritt (4) bei einer Temperatur durchgeführt wird, bei der der partiale Dampfdruck der hydrophoben Phase in der gleichen Größenordnung liegt wie der von Wasserdampf.

20. Verfahren nach Anspruch 17, in welchem die Verdampfung von Schritt (4) unter gefriertrocknenden Bedingungen durchgeführt wird.

21. Verfahren nach Anspruch 20, in welchem die Gefriertrocknung bei Temperaturen von -40° C bis 0° C durchgeführt wird.

22. Verfahren nach den Ansprüchen 17 oder 19, in welchem die hydrophobe Phase aus organischen Verbindungen mit einem Dampfdruck von etwa 133,3 N/m$^2$ (1 Torr) bei einer Temperatur im Intervall von etwa -40° C bis 0° C ausgewählt ist.

23. Verfahren nach den Ansprüchen 17 oder 18, in welchem die wäßrige Phase, gelöst, etwa 1 bis 20 Gew.-% Stabilisatoren enthält, welche hydrophile Verbindungen ausgewählt aus Zukkern, PVA, PVP, Gelatine, Stärke, Dextran, Polydextrose, Albumin und dergleichen umfassen.

24. Verfahren nach Anspruch 18, in welchem die Additive zum Steuern des Permeabilitätsgrades der Mikroballonmembran der hydrophoben Phase zugegeben werden, wobei die Geschwindigkeit der Bioabbaubarkeit des Polymers nach Injizieren der Mikroballone in Lebewesen eine Funktion des Permeabilitätsgrades ist.

25. Verfahren nach Anspruch 24, in welchem die Additive hydrophobe Feststoffe wie Fette, Wachse und Kohlenwasserstoffe hohen Molekulargewichts umfassen, wobei die Anwesenheit derselben in dem Membranpolymer der Mikroballone die Permeabilität gegenüber wäßrigen Flüssigkeiten verringert.

26. Verfahren nach Anspruch 24, in welchem die Additive amphiphatische Verbindungen, wie die Phospholipide, oder Polymere niederen Molekulargewichts umfassen, wobei die Anwesenheit derselben in dem Membranpolymer die Permeabilität der Mikroballone gegenüber wäßrigen Flüssigkeiten erhöht.

27. Verfahren nach Anspruch 18, in welchem die der Emulgierung in der Wasserphase unterworfene hydrophobe Phase auch ein wasserlösliches Lösungsmittel enthält, das beim Verdünnen in der Wasserphase während des Emulgierens dazu beiträgt, die Tröpfchengröße zu verringern, und die grenzflächige Abscheidung des Polymers auslöst bevor Schritt (4) ausgeführt wird.

28. Verwendung der Mikroballone gemäß den Ansprüchen 1 bis 14 für die Abbildung menschlicher oder tierischer Körper durch Ultraschall-Echographie.

29. Verwendung von Mikroballonen gemäß den Ansprüchen 1 bis 14 zur Leberabbildung durch Ultraschall-Echographie.

**Revendications**

1. Microballons de dimensions microniques ou sub-microniques comprenant une membrane de polymère remplie d'air ou d'un gaz, lesdits microballons pouvant être administrés sous forme de suspensions dans un liquide porteur à des patients humains ou animaux pour des applications thérapeutique ou diagnostiques, y compris l'imagerie par échographie, **caractérisés en ce que** le polymère de la membrane est un polymère synthétique déformable, résilient, et déposable interfacialement, susceptibles d'être obtenus selon les étapes consistant à :

   (1) émulsionner une phase organique hydrophobe dans une phase aqueuse de manière à obtenir des gouttelettes d'une émulsion huile-dans-eau de ladite phase hydrophobe dans ladite phase aqueuse ;
   (2) ajouter à ladite émulsion une solution d'au moins un polymère dans un solvant volatil insoluble dans la phase aqueuse de manière à ce qu'une couche dudit polymère se forme autour desdites gouttelettes,
   (3) évaporer ledit solvant volatil, de telle sorte que le polymère se dépose par précipitation interfaciale autour des gouttelettes, lesquelles setransforment ainsi en perles comportant un coeur formé de ladite phase hydrophobe encapsulé dans une membrane dudit polymère, lesdites perles étant en suspension dans ladite phase aqueuse ;

(4) soumettre ladite suspension des conditions de lyophilisation ; ladite phase hydrophobe étant choisie de façon à ce qu'elle s'évapore pratiquement simultanément avec la phase aqueuse et qu'elle soit remplacée par de l'air ou un gaz, ce par quoi on obtient des microballons secs, non collants, et facilement redispersibles ; (5) où ledit polymère peut être dissous dans ladite phase hydrophobe, de telle sorte que les étapes (2) et (3) peuvent être omises, et que la membrane polymère se forme alors par précipitation interfaciale pendant l'étape (4).

2. Les microballons de la revendication 1, dont la taille est principalement dans la gamme de 0,5 à 10 µm qui convient pour l'injection dans la circulation sanguine des êtres vivants, dans lesquels, soit la membrane est imperméable, soit elle est perméable aux liquides bioactifs ce qui augmente sa vitesse de biodégradation.

3. Les microballons de la revendication 2 dans lesquels la membrane polymère est poreuse et dont la porosité est de quelques nanomètres à plusieurs milliers de nanomètres, de préférence 50 - 2000 nm.

4. Les microballons de la revendication 2 dans lesquels la membrane, dont l'épaisseur est de 50 - 500nm, est élastique et résiste dans la circulation aux variations de pression dues aux battements cardiaques.

5. Les microballons de la revendication 1 dans lesquels le polymère de la membrane est un polymère biodégradable choisi parmi les polysaccharides, les polyaminoacides, les polylactides, polyglycolides et leurs copolymères, les copolymères des lactides-lactones, les polypeptides, les poly(ortho)esters, la polydioxannone, les poly-b-amino-cétones, les polyphosphazènes, les polyanhydrides, et les polyalcoyl(cyano)acrylates.

6. Les microballons de la revendication 1 dans lesquels la membrane est choisie parmi les dérivés d'acides polyglutamique et polyaspartique, et leurs copolymères avec d'autres acides aminés.

7. Les microballons de la revendication 6 dans lesquels les dérivés d'acides polyglutamique et polyaspartique sont choisis parmi les esters et les amides de leur fonction carboxylique latérale, lesidtes fonctions ayant les formules :

$$-(CH_2)_nCOO\text{-}CHR^1COOR \quad (I),$$

ou

$$-(CH_2)_nCOOCR^1R^2\text{-}OCOR \quad (II),$$

ou

$$-(CH_2)_nCO(NH\text{-}CHX\text{-}CO)_mNH\text{-}CH(COOH)\text{-}(CH_2)_pCOOH \quad (III),$$

où R est un substituant alcoyle ou aryle ; $R^1$ et $R^2$ désignent H ou des alcoyles inférieurs, ou bien R et $R^1$ sont reliés l'un à l'autre par un élément de liaison, substitué ou non, de manière à constituer un cycle à 5 ou 6 chaînons ; n vaut 1 ou 2 ; p vaut 1, 2 ou 3 ; m est un entier de 1 à 5 ; et X est la chaîne latérale d'un résidu d'acide aminé.

8. Les microballons de la revendication 1 dans lesquels la membrane polymère contient des additifs destinés à contrôler son degré d'élasticité, ainsi que la taille et la densité des pores permettant contrôler sa perméabilité.

9. Les microballons de la revendication 8 dans lesquels additifs comprennent des plastifiants, des substances amphipatiques et des composés hydrophobes.

10. Les microballons de la revendication 9, où les plastifiants incluent le myristate d'isopropyle, le monostéarate de glycéryle et similaires, pour contrôler la flexibilité de la membrane ; les composés amphipatiques incluent des surfactants et des phospholipides, tels que les lécithines pour contrôler sa perméabilité par augmentation de la porosité et les composés hydrophobes incluent des hydrocarbures de poids moléculaires élevé, tels que les cires de paraffine afin de réduire sa porosité.

11. les microballons de la revendication 9 où les additifs incluent des polymères de poids moléculaire situés dans la plage de 1000 à 15.000 pour contrôler la souplesse et la résilience de la membrane des microballons.

12. Les microballons de la revendication 11 dans lesquels les additifs polymères de bas poids moléculaire sont choisis parmi les polylactides, les polyglycolides, les polyalcoylène glycols comme le polyéthylène glycol et le polypropylène glycol, et les polyols comme le polyglycérol.

13. Les microballons de la revendication 1, dont la taille est d'environ 1000 µm convenant aux applications orale, rectale et uréthrale, où la membrane polymère n'est pas biodégradable dans le tube digestif et imperméable aux liquides biologiques.

14. Les microballons de la revendication 13, dans lesquels le polymère est choisi parmi les polyoléfines, les polyacrylates, le polyacrylonitrile, les polyesters non hydrolysables, les polyuréthanes et les polyurées.

15. Suspension aqueuse injectable de microballons suivant l'une des revendications 1 à 14 **caractérisée en ce que** les microballons sont présents en concentration d'environ $10^6$ à $10^{10}$ microballons/ml, ladite suspension étant stable pendant au moins 30 jours.

16. La suspension aqueuse injectable de la revendication 15 où les microballons sont entourés d'une membrane déposée interfacialement de polymère DL-lactide connu dans le commerce sous le nom de Resomer.

17. Procédé pour fabriquer des microballons remplis d'air ou d'un gaz utilisables en suspension dans un liquide porteur pour des applications orale, rectale et uréthrale, ou par injection dans des organismes vivants, ce procédé étant **caractérisé par** les étapes suivantes :

(1) on émulsionne une phase organique hydrophobe dans une phase aqueuse de manière à obtenir des gouttelettes d'une émulsion huile-dans-eau de ladite phase hydrophobe dans ladite phase aqueuse.
(2) On ajoute à ladite émulsion une solution d'au moins un polymère dans un solvant volatil insoluble dans la phase aqueuse, de manière à ce qu'une couche dudit polymère se forme autour desdites gouttelettes ;
(3) On évapore ledit solvant volatil, ce qui entraîne le dépôt du polymère par précipitation interfaciale autour des gouttelettes, lesquelles se transforment ainsi en perles comportant un coeur formé de ladite phase hydrophobe encapsulé dans une membrane dudit polymère, lesdites perles étant en suspension dans ladite phase aqueuse ;
(4) On soumet ladite suspension à pression réduite dans des conditions telles que ladite phase hydrophobe soit éliminée par évaporation ;

- **caractérisé en ce qu'**on choisit ladite phase hydrophobe de façon à ce qu'elle s'évapore pratiquement simultanément avec la phase aqueuse et qu'elle soit remplacée par de l'air ou un gaz, ce qui fournit des microballons secs, non collants, et facilement redispersibles.

18. Le procédé de la revendication 17 dans lequel le polymère est dissous dans ladite phase hydrophobe, de telle manière à ce qu'on puisse supprimer les étapes (2) et (3) et que la membrane polymère se forme par précipitation interfaciale à l'étape (4).

19. Le procédé de la revendication 17 dans lequel on effectue l'évaporation de ladite phase hydrophobe de l'étape (4) à une température telle que la pression de vapeur partielle de ladite phase hydrophobe soit de même ordre que celle de la vapeur d'eau.

20. Le procédé de la revendication 17 dans lequel, à l'étape (4), on effectue l'évaporation dans les conditions d'une lyophilisation.

21. Le procédé de la revendication 20 où on effectue la lyophilisation à une température de -40 à 0°C.

22. Le procédé des revendications 17 ou 19 dans lequel on choisit, pour réaliser la phase hydrophobe, parmi les composés organiques dont la pression de vapeur est d'environ 133,3 Nt/m2 (1 Torr) à une température comprise dans l'intervalle d'environ -40 à 0°C.

23. Le procédé des revendications 17 ou 18 dans lequel le phase aqueuse comprend, dissous, environ 1 à 20 % en

poids de stabilisants comprenant des composés hydrophiles choisis parmi les sucres, le PVA, le PVP, la gélatine, l'amidon, le dextrane, le polydextrose, l'albumine, et des composés similaires.

24. Le procédé de la revendication 18 dans lequel on ajoute à la phase hydrophobe les additifs servant à contrôler le degré de perméabilité de la membrane des microballons, le taux de biodégradabilité du polymère après qu'on ait injecté les microballons dans des organismes vivants étant fonction de ce degré de perméabilité.

25. Le procédé de la revendication 24, dans lequel lesdits additifs incluent des solides hydrophobes tels que graisses, cires, et hydrocarbures de poids moléculaire élevé, dont la présence dans la membrane polymère des microballons diminue sa perméabilité vis à vis des liquides aqueux.

26. Le procédé de la revendication 24 dans lequel lesdits additifs incluent des composés amphipatiques tels que des phospholipides ou des polymères de bas poids moléculaire dont la présence dans la membrane de polymère augmente la perméabilité des microballons aux liquides aqueux.

27. Le procédé de la revendication 18 dans lequel la phase hydrophobe qu'on émulsionne dans ladite phase aqueuse contient en outre un solvant hydrosoluble qui, lorsqu'il se dilue dans la phase aqueuse pendant l'émulsion, contribue à diminuer la taille des gouttelettes et provoque une précipitation interfaciale du polymère avant la mise en oeuvre de l'étape (4).

28. Utilisation des microballons selon l'une des revendications 1 à 14 pour l'imagerie échographique par ultrasons du corps humain ou animal.

29. Utilisation des microballons selon l'une des revendications 1 à 14 pour l'imagerie échographique par ultrasons du foie.

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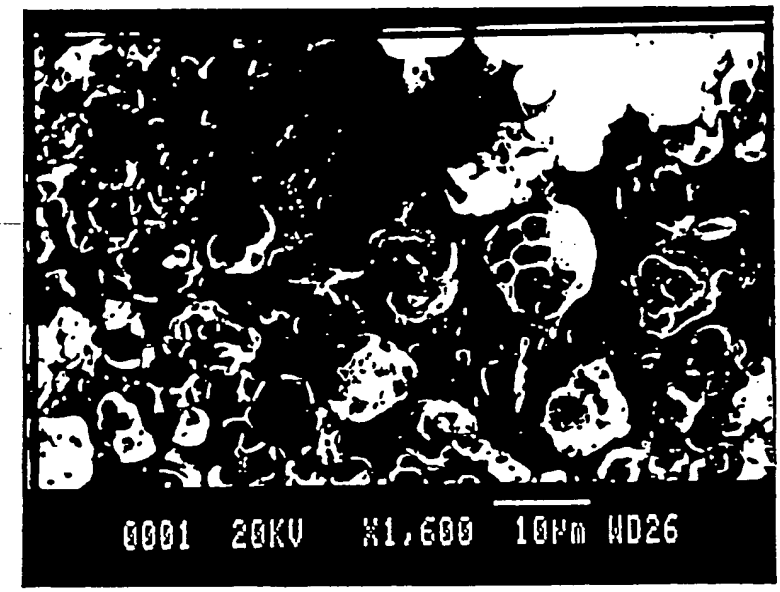


(57) Abstract

Hollow (i.e. gas- or vapour-filled) microcapsules, for example of albumin, are prepared by forming a shell around a solid or liquid core and subsequently removing the core. The core may be a volatile oil such as perfluorohexane. The shell may be made by simple or complex coacervation, oil/water/oil double emulsion, or MSIEP (minimisation of solubility at isoelectric point) methods, followed by chemical or heat hardening to render it water-insoluble. When the double emulsion method is used, the microcapsules have a honeycomb appearance with multiple gas-filled chambers. The microcapsules can be used for echocardiography.

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# DIAGNOSTIC AID

The present invention relates to diagnostic aids and, more particularly, to echogenic materials for echocardiography and other purposes.

As is known from EP-A-0 324 938, air-filled albumin microbubbles of about 1-10 μm can be injected into the bloodstream and will reflect ultrasonic radiation in such a way as to yield diagnostically-useful images of the heart and other internal organs. These microbubbles are formed by sonicating viscous aqueous albumin solutions at 5000 - 30,000 Hz. The resulting microbubbles are heat-denatured to make the albumin water-insoluble.

We have now devised an improved process for preparing hollow microcapsules, rather than microbubbles, which has been found to give a high yield of particles which are better suited for echocardiography.

One aspect of the invention provides a process for preparing gas-containing microcapsules comprising forming water-dispersible (preferably proteinaceous) microcapsules having a liquid or solid core and removing at least some of the said liquid or solid to create a microcapsule containing a gas.

Forming non-proteinaceous microcapsules in this way has previously been proposed in GB-A-1 288 583 for use in paints. The polymers used in GB-A-1 288 583 were insoluble polymers like polystyrene. There was no suggestion of their use as injectable compositions for echocardiography, whereas the compositions of the present invention, at least when used for such a purpose, are biocompatible, biodegradable and non-immunogenic.

A. Kondo in "Microcapsule Processing and Technology" (Marcel Dekker Inc, New York, 1979) suggests forming hollow capsules using a low boiling point solvent as the core in an in-liquid drying process (page 109) and oil-containing gelatin capsules from which the oil is not subsequently removed. US-A-4 173 488, US-A-3 781 230 and US-A-4 089 800 disclose the use of hydrophobic resins and hydrophobic starches to coat the oil droplets in an oil-in-water emulsion and subsequently form microcapsules. None of these documents mentions using the microcapsules for echocardiography and none mentions the use of albumin. EP-A-0 327 490 discloses the use of synthetic polymers to surround gas bubbles in a liquid medium and subsequently form microcapsules for echocardiography. This is a different process from that of the present invention and the prior specification does not mention using proteins.

The core in the process of the present invention is preferably a water-immiscible oil and is preferably also relatively volatile so that it can be evaporated after the microcapsules have been formed, in other words during or after the hardening of the wall. This is what we mean by "relatively volatile". More specifically, any inert oil, preferably a perfluoro compound, having a boiling point of 20-100°C, preferably 40-90°C and more preferably 50-80°C is generally suitable. Perfluorohexane, perfluoroheptane, perfluoromethylcyclohexane, cyclopentane, hexane, 2-methylpentane, 3-methylpentane, 2,2, dimethylbutane, 2,3, dimethylbutane, 1-chloropropane, 2-chloro-2-methyl propane, chloroform, methylene chloride, 1,1 dichloroethane and bromoethane are all suitable. More than one core can be provided in each microcapsule. A solid core, such as ammonium carbonate, may be used, followed by sublimation or removal with a solvent.

The process for the production of hollow microcapsules may be any of those generally known as simple coacervation, complex coacervation, MSIEP (minimisation of solubility at isoelectric point) and double emulsion, but is preferably the latter. Interfacial polymerisation may be used for some wall-forming materials, although not for proteinaceous materials.

Any suitable wall-forming material may be used which is (i) dispersible (preferably soluble) in water, (ii) capable of being rendered water-insoluble once the microcapsules are made and (iii) physiologically non-toxic and non-immunogenic, at least in the conditions of use. Materials which are biodegradable in the patient following administration are preferred. Proteinaceous materials are preferred and serum albumin is generally suitable. The term "proteinaceous" is used herein to describe proteins, naturally-occurring and synthetic polypeptides and fragments of proteins and polypeptides. For human use, human serum albumin (HSA) is preferred. This can be isolated from serum by known techniques or manufactured by recombinant DNA techniques such as are disclosed in EP-A-201 239 and EP-A-286 424. Analogues and fragments of HSA can be used, such as are disclosed in EP-A-322-094. In this specification, the term "albumin" is used to cover all of these compounds. Other materials include gelatin, hydroxyethyl starch, starch and dextran. The properties of some materials, such as albumin, may be modified by the presence of an added non-ionic surfactant, such as is described by Omotosho *et al* as interfacial complexation (1986 *J. Pharm. Pharmacol.* 38, 865-870). The materials are chemically or thermally denatured, to render them insoluble, after the microcapsules have been formed.

The (preferably proteinaceous) material can be made water-insoluble by chemical cross-linking, denaturation (for example with heat), chelating or grafting.

The microcapsules of the invention are filled with a gas or vapour, which may be air or any other true gas but is often a mixture of air and the vapour from the volatile oil. In this specification, the term "air-filled" is loosely used to cover pure air, any other gas, any vapour or mixtures thereof.

The microcapsules which are formed are preferably from 0.1 to 500 μm in diameter. For use in echocardiography, a range of 1.0 to 10 μm or 2.0 to 8 μm is especially suitable. Such sizes may be achieved by appropriately selecting the process parameters and/or by separating out, for example by wet micro-sieving or air elutriation, the desired size from the resulting microcapsules. Since a range of sizes will usually result, the figures in this specification refer to 90% of the population by weight. The size range can be measured with a light microscope or by using known apparatus such as the Coulter Counter and known methods such as those disclosed in Morris & Warburton, *J. Pharm. Pharmacol.* 36, 73-76 (1984).

At least in the case of the double emulsion methods, a multi-chamber microcapsule results, resembling a honeycomb or the type of confectionery sold in the UK under the registered trademark

"Malteser". This is a preferred product. There may be from two to several hundred chambers in each microcapsule, preferably at least 10.

The final product is typically obtained in the form of a suspension which may be washed, sterilised and used. In at least some cases, however, the microcapsules can be freeze-dried without collapsing and stored as a free-flowing powder for future use.

The air-filled microcapsules may be used in echocardiography and other ultrasonic imaging techniques in ways known in the art (see, for example, EP-A-0 324 938, US-A-4 276 885 and US-A-4 572 203, all incorporated by reference), in nasal and lung delivery systems for drugs (when prepared as powder, rather than suspensions) and as opacifiers or reflectivity enhancers in cosmetics.

The air-filled microcapsules themselves (especially the multi-chamber capsules) and their uses, particularly as echogenic materials in diagnostic procedures, form further aspects of the invention.

Examples of the invention will now be given with reference to the accompanying figures, in which:

Figures 1 and 2 are views from above and one side of respective stirring paddles;

Figure 3 is a vertical section of a mixing vessel in which the paddles operate; and

Figures 4 and 5 are respective scanning electron micrographs of microcapsules prepared in accordance with the invention using the double emulsion method.

EXAMPLE 1: SIMPLE COACERVATION

This method was adapted from one described in US Patent 2,800,458 (1957), for the production of carbonless copying paper. Various volatile oils were homogenised using a hand homogeniser (room temp., 15 mins) with 20 ml of a 10% aqueous solution of albumin, to form an o/w emulsion. Initially 1 ml of the oil perfluoro-1,3-dimethyl cyclohexane, which has a boiling point of 101-102°C, was used. Other oils such as dichloromethane (B.P. 39.8 - 40°C) and perfluorohexane (B.P. 58 - 60°C) were later employed. A dehydrating agent (isopropanol (6 ml) or a salt eg 6 ml of 20% sodium sulphate can be used) was then added over 10 mins, to induce coacervation, or concentration of the albumin around the droplets of volatile oil, and the product was stirred for 1 hour at 1233 rpm. A surfactant (Span 80 (sorbitan mono-oleate); 0.2 ml; was added

after coacervation and before cross-linking to prevent agglomeration of the microcapsules following cross-linking. The albumin was cross-linked using glutaraldehyde (0.2 ml) and excess reagent was inactivated with sodium metabisulphite (0.4 ml of 12% aqueous solution), which reacts with free aldehyde groups. The suspension of microcapsules obtained was stored in a desiccator at 5°C. The capsules were sized using a Malvern 3600 particle sizer.

Using this method, microcapsules were produced. Most were much smaller than 5 μm in diameter. By reducing the stirring speed from 1233 to 874 rpm, using perfluoro-1,2-dimethyl cyclohexane as volatile oil and Span 80 as surfactant, the yield of microcapsules in the size range 2 - 8 μm was increased but the range was also broader. When the surfactant was changed to Pluronic F68, the proportion of microcapsules in the desired size range increased to 71.7%; however, the range was still broad. (Pluronic F68 is the trade designation for poloxamer 188 (poloxalkol), a block copolymer of polyoxyethylene and polyoxypropylene (CAS-9003-11-6).) The nature of the volatile oil was also found to affect the particle size, with dichloromethane and perfluorohexane both producing smaller microcapsules than perfluoro-1,3-dimethyl cyclohexane, under the same conditions.

EXAMPLE 2: SIMPLE COACERVATION

The basic method of Example 1 was followed. 1 ml of perfluorohexane was homogenised into 10 ml of a 10% aqueous albumin solution in 30 sec using a Silverson homogeniser at 6800 rpm, following by stirring at 1370 rpm for 15 mins, at room temperature. The isopropanol was added as before but this step was followed by stirring for 1.5 hours at 1370 rpm. Similarly, the additions of Span 80 and glutaraldehyde were each followed by 15 min of stirring at 1370 rpm instead of 1233 rpm. Excess glutaraldehyde was removed with ethanolamine (0.8 ml) and the final stirring was at 1370 rpm for 15 min. The product was obtained as a suspension of relatively uniform microcapsules in the desired range of 2 - 8 μm.

EXAMPLE 3: DOUBLE EMULSION METHOD

A primary o/w emulsion was produced by homogenising a volatile oil (perfluoro-1,3 dimethyl cyclohexane) with a solution of HSA, as in Example 1. This emulsion was then re-emulsified into olive oil to produce an o/w/o emulsion, with the volatile oil as the inner oil phase. After addition of a surfactant, Pluronic F68, to prevent agglomeration of the particles, glutaraldehyde was added to cross-link the albumin. The excess glutaraldehyde was then inactivated using sodium metabisulphite. The resulting microcapsules were separated by centrifugation and washed with

petroleum ether and acetone, to remove the olive oil. After drying overnight in a desiccator at room temperature, the microcapsules were collected as a dry powder. Details of the method are as follows.

0.5 ml perfluoro-1,3-methylcyclohexane was homogenised into 1 ml of 20% aqueous HSA solution over 5 min at 6800 rpm. This o/w emulsion was poured into 25 ml of previously stirred olive oil and stirred at room temperature for 15 min at 1233 rpm. 0.4 ml of 10% Pluronic F68 was added and stirred for 15 min at 1233 rpm. 0.2 ml of glutaraldehyde was added and stirred as before. 0.4 ml of 12% aq. sodium metabisulphite added and stirred as before. The product was centrifuged at 3000 rpm for 20 min and washed etc as above.

Hollow microcapsules of 20-100 μm were obtained.

EXAMPLE 4: DOUBLE EMULSION

15 ml of perfluorohexane (Aldrich, UK) was added to 30 ml of 10% (w/v) HSA solution (fraction V; Sigma, UK) and emulsified with a Microfluidizer (Microfluidics Corporation, Newton, Mass, USA) in a continuous process for 45 seconds to form an o/w emulsion. 1.5 ml of this emulsion was then added to 50 ml of soya oil (Sainsbury, UK) at 22°C and emulsified with a homogenizer (Silverson, UK) at 6800 rpm for 5 minutes. The resultant o/w/o

emulsion was transferred to an oil bath and then heated at 120°C for 30 minutes, while the mixture was stirred using a mechanical stirrer (Heidolph RZR-1) at 874 rpm.

The mixture was allowed to cool to 25°C. Once this temperature had been reached, 20 ml of petroleum ether (May & Baker, UK) was added to the microsphere-soya oil suspension. This mixture was centrifuged at 3000 rpm for 20 minutes. The supernatant was decanted and the microspheres were washed with 40 ml of petroleum ether, centrifuged, decanted; washed again with petroleum ether and finally with ethanol.

Differing conditions were tried, for example using a mechanical stirrer or a homogenizer for the o/w/o emulsion; 1, 2 or 3% o/w emulsion in the soya oil; olive instead of soya oil; 874, 1250 or 2000 rpm stirring speed; type of paddle; 16.7 or 33.3% volatile oil; non-volatile oil (n-dodecane) instead of volatile oil; 5, 10 or 20% HSA; and 0, 1 or 10% lecithin as a surfactant in the primary emulsion.

Preferred conditions included: using a homogenizer to prepare the primary emulsion using 1% or 2% o/w emulsion in the soya oil; using soya instead of olive oil; using a vertical paddle as shown in Figure 2 at 2000 rpm, optionally with baffles in the mixing vessel; using volatile or non-volatile oil at 33.3%; absence of lecithin.

All particles were sized using a laser diffraction technique (Malvern Particle Sizer Type 2600 D, Malvern Instrument, UK). The particles were resuspended in water and sonicated (Soniprobe 7532B, Dawe, UK) for 2 minutes at 60 W before sizing. The shape and possible agglomeration of the particles were studied using a light microscope (Optiphot, Nikon, Japan). The product was a free flowing powder of size range 2-20 μm.

EXAMPLE 5: DOUBLE EMULSION

The method of Example 4 was adapted as follows to produce a particularly satisfactory result. 10 ml of perfuorohexane was emulsified into 20 ml of 10% aq. HSA with Microfluidiser, circulating the liquid three times at 60 - 90,000 kPa. 1 ml of o/w emulsion was poured into 50 ml soya oil and homogenised with the Silverson blender for 5 min at 6800 rpm. The albumin was cross-linked by heating to about 120°C in an oil bath (15 min equilibration; 30 min heating) whilst paddle stirring at 2000 rpm and then cooled to room temperature, followed by paddle stirring at 2000 rpm whilst adding 20 ml petroleum ether. The product was paddle stirred at 2000 rpm for 2 min, centrifuged at 3000 rpm for 20 min, decanted, washed twice with ether (20 ml) and once with ethanol (20 ml), shaken, centrifuged and decanted. Finally, the product was freeze-dried.

The product was a free-flowing powder of 2-10 μm microcapsules.

EXAMPLE 6: MINIMIZATION SOLUBILITY AT ISOELECTRIC POWER (MSIEP)

A method was developed for producing albumin microcapsules by the MSIEP technique. The preliminary results obtained by this method are discussed below. The MSIEP method uses elements of both complex coacervation and simple (o/w) emulsion techniques.

1 ml of perfluorohexane was emulsified with 10 ml of 10% HSA solution with a Silverson or microfluidiser to give a primary o/w emulsion to which 10 ml of 5% or 10% aq. HSA solution (pH 6.65) was added at room temperature, whilst stirring at 800 rpm. By decreasing the pH of the mixture to <4.7 with 1M HCl, whilst stirring at 800 rpm, the albumin in the mixture comes out of solution at the isoelectric point and forms a coating around the emulsion droplets due to neutralization of charges on the surface of the albumin in the emulsion and the solution. The albumin coating can then be cross-linked by heat or a chemical method(s) as described above. If glutaraldehyde is used to cross-link the albumin (typically 1 ml of 25% solution) then excess glutaraldehyde can be removed with 2 ml of ethanolamine (free base).

EXAMPLE 7: COMPLEX COACERVATION

This is a modification of a known method for the preparation of non-hollow microcapsules (see for example US 4808408, incorporated herein by reference). It relies upon the interaction of polymers in solution carrying opposite charge. Albumin (isoelectric point 4.7) which will carry a negative charge at pH 6.3 may be combined with a gelatin (isoelectric point in the range 7 to 9), which will carry a positive charge at this pH. Other suitable polymer mixtures may be used provided one is negative and the other positive at the chosen pH. For example, at low pH (4.0) albumin will be positively charged and may be made to interact with a negatively charged polymer (eg sodium alginate) or type B gelatin (isoelectric point 4.7-5.0). The choice of the complexing material for albumin will be based upon toxicity considerations.

More specifically, an oil-in-water emulsion was formed from 10 ml of 10% HSA (pH 6.3) and 1 ml perfluorohexane by Silverson blending for 5 mins at 6800 rpm, and then stirred at 638 rpm for 10 mins at 45°C. 10 ml of 10% gelatin type A (pH 5.9) was slowly added to give a preparation at pH 6.3 which was stirred as before. 0.4 ml of Span 80 was added and the mixture was stirred as before, following which 0.1 ml of 37% aqueous formaldehyde (cross-linker) was added and the mixture was stirred as before. Finally, 0.2 ml of 12% w/v sodium

metabisulphite was added to quench the formaldehyde and the mixture was stirred as before. A suspension of 2-50 μm microspheres was obtained.

The microcapsules may be filtered, washed and dried.

EXAMPLE 8: DOUBLE EMULSION

Materials: 25% Human Serum Albumin (HSA) Alpha Therapeutic Corporation, Los Angeles, USA. Soya oil (edible grade) J. Sainsbury plc. Petroleum ether Bpt 60-90C°(AR) Fisons, Loughborough, UK. Ethanol Absolute (AR) Fisons, Loughborough, UK. Acetone (AR) Fisons, Loughborough, UK. Fluorophore Filters (0.5 μm pore size), Millipore Filters.

Volatile oils: Perfluorohexane (99%) Aldrich Chemicals Ltd, UK. Perfluorodecaline Rhone Poulenc ISC Division, Avonmouth, Bristol. Perfluorodimethylcyclohexane Aldrich Chemicals, UK. Perfluoromethylcyclohexane Aldrich Chemicals, UK.

Instrumentation: Microfluidiser 120E, Christison Scientific Equipment Ltd, Gateshead, UK. Silverson homogeniser L4R, NorthernMedia, Nottingham. Homogeniser heads: Coarse head (2 mm circular pores), Fine head (1 mm circular pores), Heidolph stirrer ST1. Stirrer heads: 6-blade turbine, 4-blade paddle, 4-blade rotor.

Method: Emulsion formulations: Primary emulsion, 20 ml HSA (10%), 10 ml volatile oil.

Secondary emulsion: 15 ml primary emulsion, 500 ml Soya oil.

Preparation of the primary emulsion. The HSA and the volatile oil, which was any of those listed above or a combination of two in varying proportions, were mixed. The mixture was then emulsified using the microfluidiser or the Silverston homogeniser. The Microfluidiser was used at an operating pressure of 5.5-9.7 x $10^7$ $N/m^2$ (8000-14000 pounds per square inch). The homogeniser was operated at 5000-9000 revolutions per minutes (rpm). The emulsion was manufactured in the microfluidiser either with or without the cooling coil. It was processed through 1-4 cycles. With the homogeniser, the volumes of the formulation were scaled up by a factor of 4 to make up the minimum homogenisation volume. The emulsion was then homogenised for 1-4 minutes. The emulsion was used as soon as possible after manufacture or stored at 4°C for use after a few hours.

Prepartion of the secondary emulsion and heat-fixing. 15 ml of the primary emulsion was added to 500 ml of soya oil and homogenised at 5500 rpm for 3 minutes. The emulsion was then transferred to a heated oil-bath and heated at the rate of 1 or 2°C per minute. The emulsion was stirred continuously during

heating using one of the stirrer heads described above at speeds which varied between 600-1500 rpm. The emulsion was heated to 120°C and held there for 20 minutes. The emulsion was then allowed to cool at room temperature and the microcapsules were harvested.

About 100 ml of petroleum ether was added to the fixed emulsion and stirred. The mixture was then centrifuged at 4500 rpm for 20 minutes. The supernatant was discarded and the pellet collected. The pellet was then resuspended in ether and passed vacuum-filtered through a 0.5 μm pore Fluorophore filter. The pellet was washed with ether, ethanol and acetone successively. The dry filter-cake was then allowed to dry at ambient temperature in a desiccator and then freeze-dried and stored at room temperature.

The size of the pores within the microcapsules depended on the volatile oil and the method of homogenisation used in the manufacture of the primary emulsion. Perfluorodecalin in conjunction with the Microfluidiser tended to produce microcapsules with an interior having a plurality of hollow spaces, resembling a "Malteser" sweet. ("Malteser" is a registered trademark.) Perfluorohexane emulsions made using the Microfluidiser tended to be solid while perfluorohexane emulsions made using the Silverson homogeniser were thin-walled microspheres with 5-10 pores per microcapsule. Flow charts for

two methods are given in Tables 1 and 2 below. Scanning electron micrographs of the product are shown in Figures 4 and 5. In Figure 4, the microcapsules have been prepared as follows: 1° emulsion: 60 ml 10% HSA, 30 ml Perfluorodecalin, microfluidised at 4.8 x $10^7$ N/$m^2$ (7000 psi), 4 cycles, and homogenised at 6500 rpm for 5 minutes. 2° emulsion: 15 ml of the 1° emulsion was added to 500 ml soya oil and homogenised at 5500 rpm for 3 mins. The emulsion was stirred at 1500 rpm using a 6-blade stirrer head. The sample was freeze-dried before microscopy. In Figure 5, the microcapsules have been prepared as follows: 1° emulsion: 20 ml 10% HSA, 10 ml Perfluorodecalin, microfluidised at 9.7 x $10^7$ N/$m^2$ (14000 psi), 4 cycles. 2° emulsion: 15 ml of the 1° emulsion was added to 500 ml soya oil and homogenised at 5500 rpm for 3 mins. The emulsion was stirred at 3000 rpm using a 6-blade stirrer head. The sample was freeze-dried before microscopy.

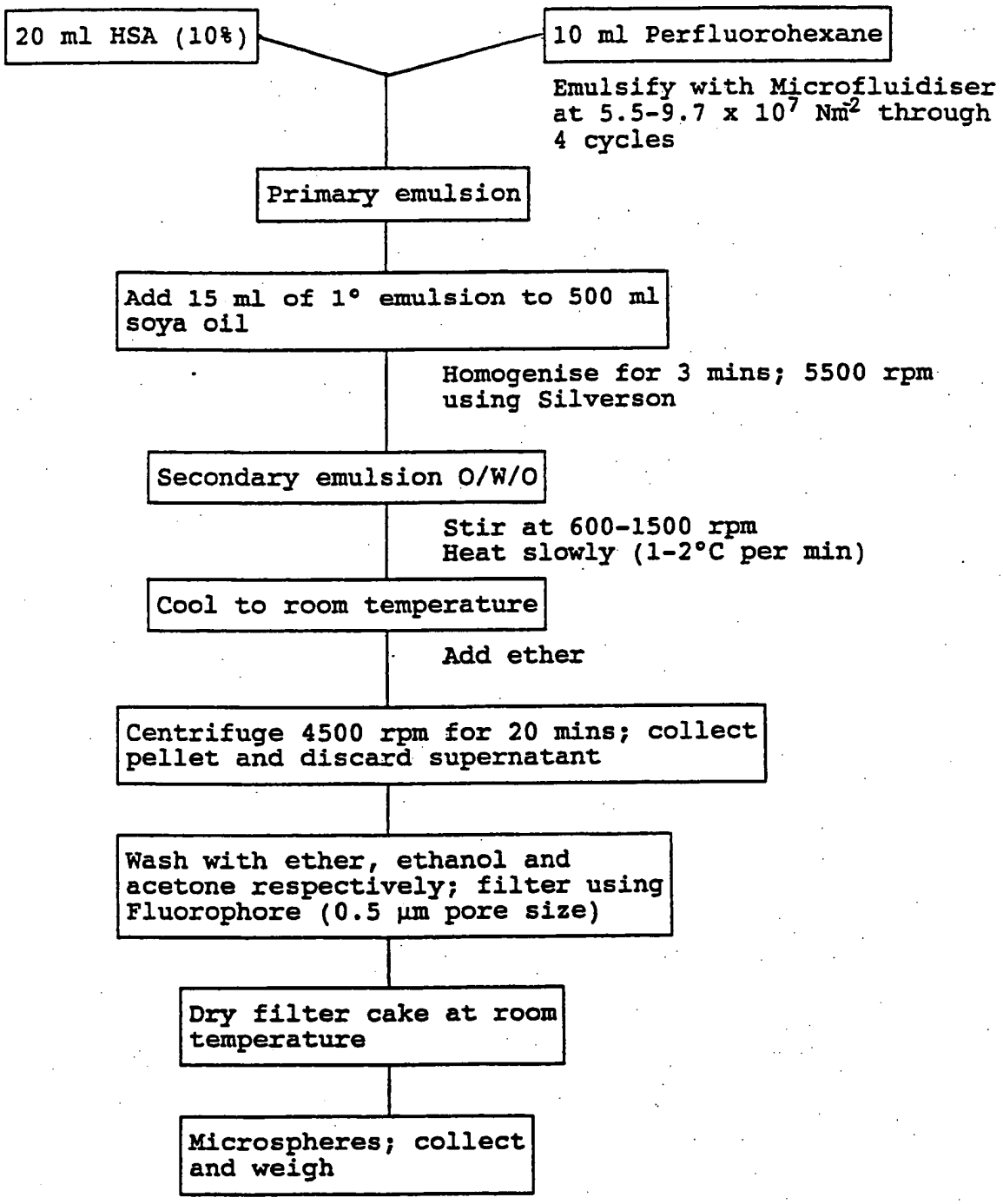


Table 1

**Scaled-up process for the manufacture of HSA microcapsules using the double emulsion method (A).**

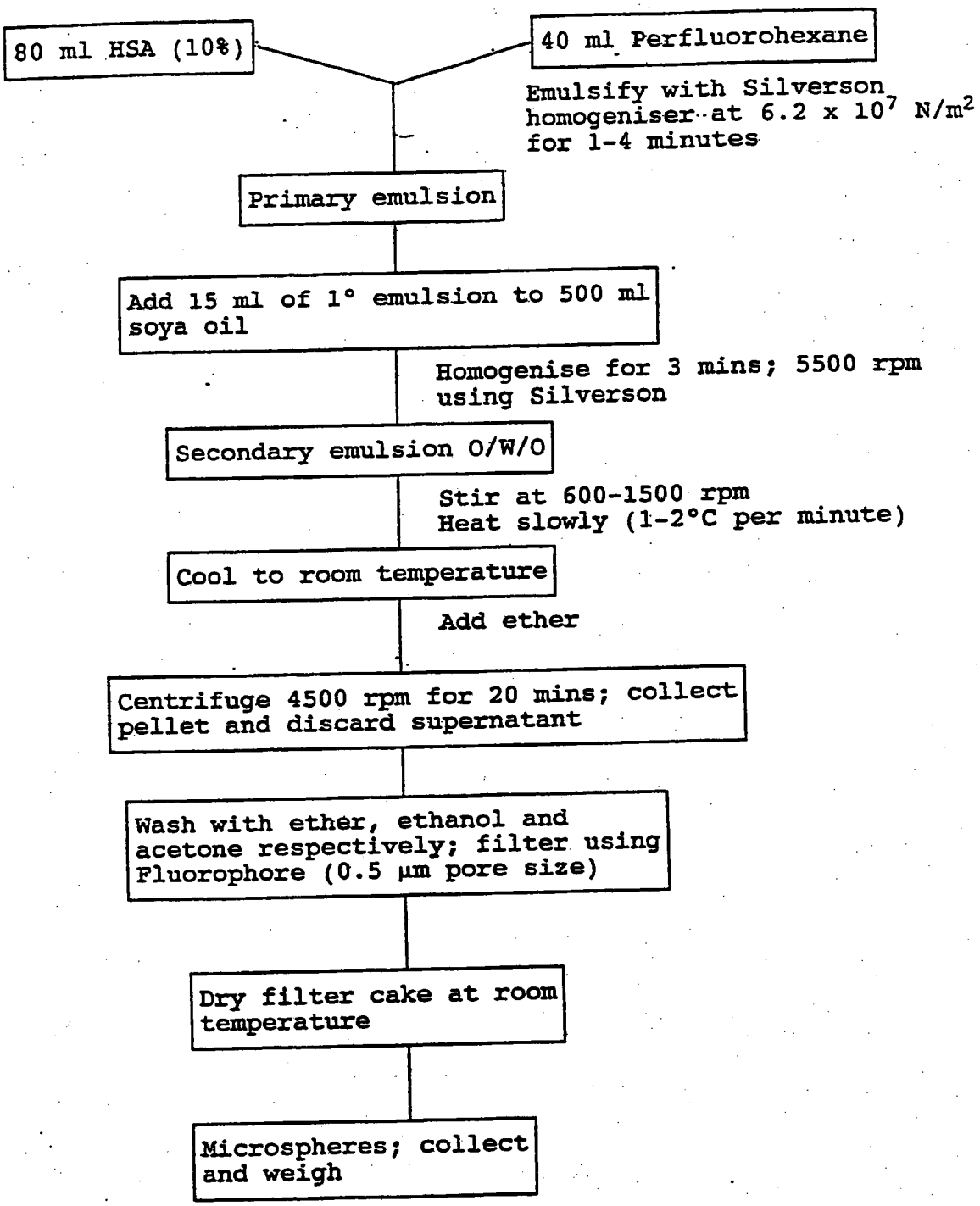


Table 2

Scaled-up process for the manufacture of HSA microcapsules using the double emulsion method (B).

GENERAL

The whole process of the invention can advantageously be carried out aseptically, starting with raw materials filtered through 0.22 μm filters so that no subsequent sterilisation is needed. Alternatively, established methods such as the use of moist heat (autoclave), ethylene oxide or gamma irradiation may be used.

The final product will preferably be prepared as a powder which will be reconstituted by the addition of sterile water for injection of sterile saline and then administered by intravenous injection. The powder may contain a suitable wetting agent such as Poloxamer 188 to aid redispersion, if needed.

CLAIMS

1. A process for preparing gas-containing microcapsules comprising forming microcapsules from a water-dispersible material, the microcapsules containing a liquid or solid core, and removing at least some of the said liquid or solid to create a microcapsule containing a gas.

2. A process according to Claim 1 wherein the water-dispersible material is water-soluble.

3. A process according to Claim 2 wherein the microcapsule walls are formed from water-soluble proteinaceous material and are subsequently made water-insoluble.

4. A process according to Claim 3 wherein the proteinaceous material is albumin.

5. A process according to any other of the preceding claims wherein the said core is a water-immiscible oil.

6. A process according to Claim 5 wherein the oil is relatively volatile and is removed from the oil-filled capsules by evaporation.

7. A process according to any other of the preceding claims wherein the microcapsules are formed by simple coacervation.

8. A process according to any one of Claims 1 to 6 wherein the microcapsules are formed by complex coacervation.

9. A process according to any one of Claims 1 to 6 wherein the microcapsules are formed by the process known as minimisation of solubility at isoelectric point.

10. A process according to any one of Claims 1 to 6 wherein the microcapsules are formed by a double-emulsion process.

11. A process according to any one of the preceding claims further comprising separating the gas-filled microcapsules from any liquid medium and freeze-drying the micro-capsules.

12. Microcapsules prepared by or obtainable by a process according to any one of the preceding claims.

13. A gas-filled microcapsule for use in diagnostic procedures, the gas-filled microcapsule having been formed by forming a microcapsule around a solid or liquid core and removing at least part of the said solid or liquid core.

14. A microcapsule having a plurality of gas-filled chambers therein.

15. A method of forming a diagnostic image comprising adding the microcapsules of any one of Claims 12 to 14 to the bloodstream of a patient, reflecting ultrasonic waves off the micro-capsules as they pass through or lodge in an organ to be imaged, and forming an image from the reflected waves.

16. A pharmaceutical composition for administration to the body comprising gas-filled microcapsules according to any one of Claims 12 to 14.

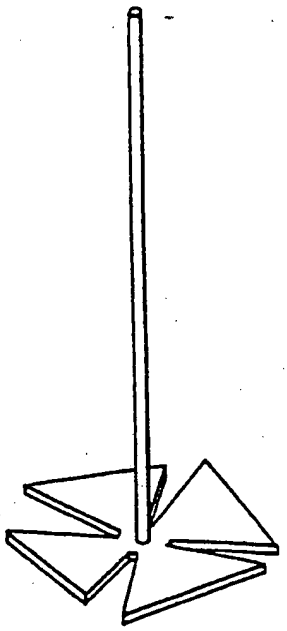

Fig. 1

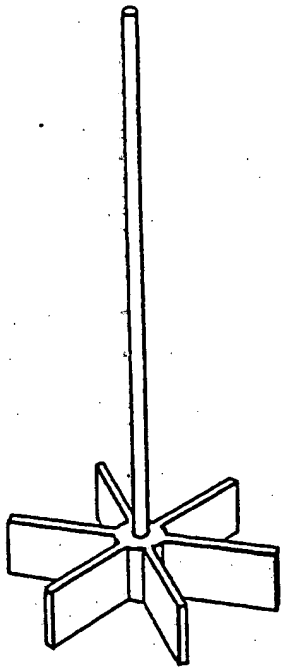

Fig. 2

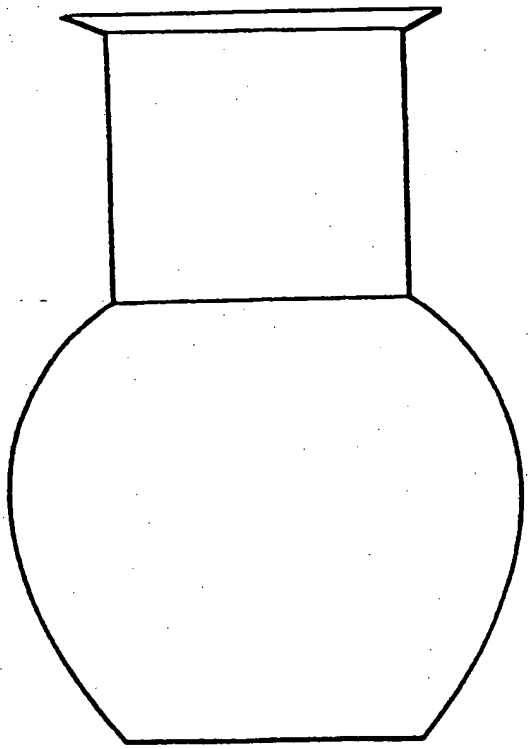

Fig. 3

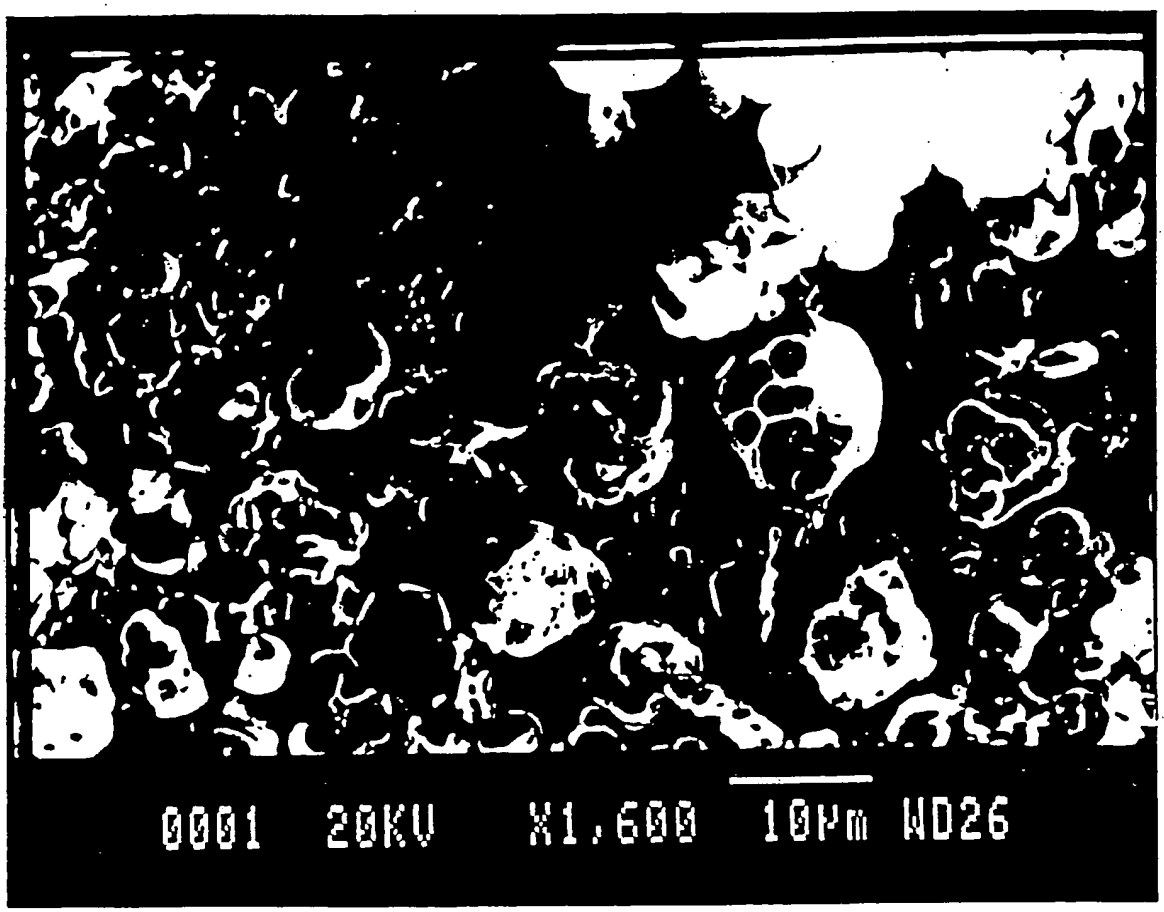


Figure 4

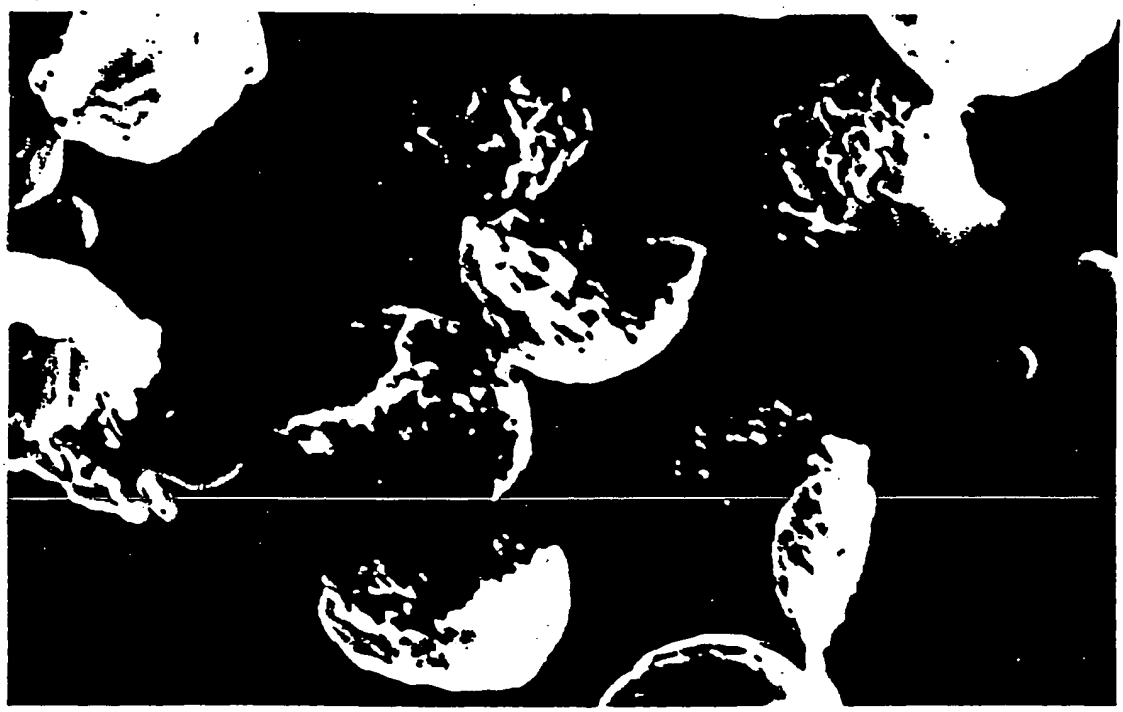

Figure 5

# INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 91/00247

## I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[5]: A 61 K 49/00, B 01 J 13/20, A 61 K 9/50

## II. FIELDS SEARCHED

Minimum Documentation Searched [7]

| Classification System | Classification Symbols |
|---|---|
| IPC[5] | A 61 K, B 01 J |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

## III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

| Category [10] | Citation of Document, [11] with indication, where appropriate, of the relevant passages [12] | Relevant to Claim No. [13] |
|---|---|---|
| X | US, A, 3781230 (A.E. VASSILIADES et al.) 25 December 1973 see column 3, line 8 - column 4, lines 2,47 - column 5, lines 2,47 - column 6, line 8; column 10, lines 20-75; example 12 cited in the application | 1-13,16 |
| X | US, A, 4173488 (A.E. VASSILIADES et al.) 6 November 1979 see column 1, lines 12-17; column 1, line 40 - column 2, line 37; column 3, line 47 - column 4, line 37; example 1 | 1,2,5,6,11-13,16 |
| Y | cited in the application | 1-4,7-10 |
| X | US, A, 4089800 (R.G.TEMPLE) 16 May 1978 see column 2, lines 5-25; column 7, line 28 - column 8, line 30; column 8, line 52 - column 9, line 6; claims 1-8 | 1,2,5,6,11-13,16 |

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

## IV. CERTIFICATION

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| 2nd May 1991 | 10. 07. 91 |
| **International Searching Authority** | **Signature of Authorized Officer** |
| EUROPEAN PATENT OFFICE | Nicole Wynberg |

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

| Category * | Citation of Document, 11 with indication, where appropriate, of the relevant passages | Relevant to Claim No. |
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| Y | cited in the application | 1-4,7-10,13, 14,16 |
| Y | EP, A, 0327490 (SCHERING A.G.) 9 August 1989 see column 2, line 11 - column 4, line 52; example 1 cited in the application | 13,16 |
| Y | A. Kondo: "Microcapsule Processing and Technology", 1979, Marcel Dekker, Inc. New York, US, see pages 18-20; page 61, table 7.1; pages 68,70,90-92,106-109,118-119 cited in the application | 1-4,7-10,14 |
| P,X | Database WPIL, Derwent 90-354613 & US, A, 4968562 (DELGADO J), 6 November 1990 see abstract | 14 |

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. [X] OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. [X] Claim numbers 15, because they relate to subject matter not required to be searched by this Authority, namely:

See PCT-Rule 39.1.(iv): methods for treatment of the human or animal body by surgery or therapy as well as diagnostic methods

2. [ ] Claim numbers ....., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claim numbers....., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. [ ] OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. [ ] As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

[ ] The additional search fees were accompanied by applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

# ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9100247 SA 45006

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 11/06/91 The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

| Patent document cited in search report | Publication date | Patent family member(s) | | Publication date |
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| | | US-A- | 3779957 | 18-12-73 |
| | | US-A- | 3781230 | 25-12-73 |
| US-A- 4089800 | 16-05-78 | None | | |

# ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9100247 SA 45006

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 11/06/91 The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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| | | AU-A- | 3035189 | 25-08-89 |
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| | | EP-A- | 0398935 | 28-11-90 |